

1-2004

## Review of Spokane River Model for Washington Department of Ecology

Chris Berger

*Portland State University*

Robert Leslie Annear

*Portland State University*

Scott A. Wells

*Portland State University*

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### Citation Details

Berger, Christopher J.; Annear, Robert L., Jr.; and Wells, Scott A., "Review of Spokane River Model for Washington Department of Ecology," (2004) Technical Report EWR-01-04, Portland State University Department of Civil Engineering

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# **Review of Spokane River Model for Washington Department of Ecology**



By

Christopher J. Berger,

Robert L. Annear Jr.,

Scott A. Wells

College of Engineering and Computer Science  
Department of Civil Engineering  
Portland State University  
Portland, Oregon 97201-0751

Technical Report EWR-01-04

Prepared for the Department of Ecology, Olympia, Washington  
Project Manager: Bob Cusimano

January 2004

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## ***Introduction***

This memorandum discusses changes made to the Spokane River model calibration since the original calibration of the model discussed in the following reports: Annear et al. (2001), Berger et al. (2002), Slominski et al. (2002), and Berger et al. (2003). The first group of refinements was made by the Washington Department of Ecology. Additional changes were made by Portland State University (PSU) and were discussed in this report along with the results of two alternative calibrations. The last section displays the original calibration results from Berger et al. (2003) as a basis for comparison to the changes made by Ecology and PSU.

## ***Changes by Washington Department of Ecology***

This section itemizes changes made by Ecology from the original 2001 calibration done by PSU documented in Berger et al. (2003). A file-by-file comparison was made of each input file to the model.

## **Addition of Algal compartments and a CBOD compartments**

Two new algal compartments have been added along with a new CBOD compartment. There are now a total of three algal compartments and six CBOD compartments. The new CBOD compartment is used to simulate CBOD originating at the upstream boundary condition (the WA-ID state line), whereas the 5<sup>th</sup> CBOD compartment is still used for CBOD from the tributaries Hangman Creek, Coulee Creek and the Little Spokane River.

## **Algae coefficients**

The two new algal compartments each required a set of growth parameters. The old algal section in the control file was

ALGAL RATE	AG	AR	AE	AM	AS	AHSP	AHSN	AHSSI	ASAT
Alg 1	1.5	0.04	0.04	0.10	0.20	0.003	0.014	0.000	40.0
ALGAL TEMP	AT1	AT2	AT3	AT4	AK1	AK2	AK3	AK4	
Alg 1	8.0	10.0	20.0	30.0	0.1	0.99	0.99	0.10	
ALG STOICH	ALGP	ALGN	ALGC	ALGSI	ACHLA	APOM	ANEQN	ANPR	
Alg 1	0.005	0.08	0.45	0.00	130.00	0.8	2	0.001	

While the new section containing two new algal compartments look like this:

ALGAL RATE	AG	AR	AE	AM	AS	AHSP	AHSN	AHSSI	ASAT
Alg 1	1.5	0.04	0.04	0.10	0.20	0.003	0.014	0.000	40.0
Alg 2	1.5	0.04	0.04	0.10	0.20	0.003	0.014	0.000	75.0
Alg 3	1.7	0.04	0.04	0.10	0.10	0.003	0.014	0.000	125.0

ALGAL TEMP	AT1	AT2	AT3	AT4	AK1	AK2	AK3	AK4
Alg 1	8.0	10.0	14.0	16.0	0.1	0.99	0.99	0.10
Alg 2	10.0	16.0	20.0	25.0	0.1	0.99	0.99	0.10
Alg 3	20.0	25.0	35.0	40.0	0.1	0.99	0.99	0.10

ALG STOICH	ALGP	ALGN	ALGC	ALGSI	ACHLA	APOM	ANEQN	ANPR
Alg 1	0.005	0.08	0.45	0.00	130.00	0.8	2	0.001
Alg 2	0.005	0.08	0.45	0.00	130.00	0.8	2	0.001
Alg 3	0.005	0.08	0.45	0.00	130.00	0.8	2	0.001

Two parameters for the first algal compartment were changed. The temperature coefficient AT3 was changed from 20° C to 14° C and AT4 was changed from 30° C to 16° C. This narrowed the optimum range for growth of algal species 1, but the addition of the other algal species with higher temperature limitation coefficients insured that there would still be algae growth at warmer temperatures. This is necessary once the model user goes from one mixed assemblage of algae to individual algal groups. The temperature rate multipliers were chosen to be representative of diatoms, greens, and cyanobacteria, respectively.

The oxygen stoichiometry for algal productivity was changed from the default value of 1.4 to 1.7 for the first algal group. This was the value also used for the second and third algal groups.

## Epiphyton coefficients

The epiphyton growth rate was decreased from 1.5 day<sup>-1</sup> to 1.2 day<sup>-1</sup>. The effects of epiphyton productivity were most noticeable in shallow river sections where the reduction in growth rate decreased biomass along with the magnitude in diurnal swings of pH and dissolved oxygen. In the deeper waters of Long Lake the impact of epiphyton was less pronounced because production was dominated by phytoplankton rather than epiphyton.

The epiphyton growth temperature multiplier EK1 was changed from 0.1 to 0.3. This temperature multiplier corresponds to the value of ET1 which was set to 1 °C. The change permitted greater epiphyton productivity at very low temperatures. This allows the model to better represent supersaturated dissolved oxygen in the winter months in the Spokane River.

## CBOD

The new CBOD group, used to represent organic matter inflows from the upstream boundary, was given a decay rate identical to that used for the tributaries (0.066 d<sup>-1</sup>).

The CBOD phosphorus stoichiometry was change from the default values:

CBOD STOIC	BODP	BODN	BODC	BODSI
1CBOD	0.005	0.08	0.45	0.18
2CBOD	0.005	0.08	0.45	0.18
3CBOD	0.005	0.08	0.45	0.18
4CBOD	0.005	0.08	0.45	0.18
5CBOD	0.005	0.08	0.45	0.18

to values derived from sampling data:

CBOD STOIC	BODP	BODN	BODC	BODSI
1CBOD	0.020	0.08	0.45	0.18
2CBOD	0.002	0.08	0.45	0.18
3CBOD	0.002	0.08	0.45	0.18
4CBOD	0.016	0.08	0.45	0.18
5CBOD	0.011	0.08	0.45	0.18
6CBOD	0.003	0.08	0.45	0.18

The changes are listed in Table 1. In Table 1, the column labeled PSU Estimated BODP was an attempt to replicate the DOE BODP stoichiometry from measured data as a check on their calculation. For the point sources the estimated BODP was calculated with the following relationship:

$$BODP = \frac{\text{TotalP} - \text{PO4P}}{CBOD_u}$$

For the upstream boundary and tributaries the phosphorus component contained in algal biomass also had to be considered giving the following equation for BODP:

$$BODP = \frac{\text{Total P} - \text{PO4P} - \text{Algae} * \text{ALGP}}{CBOD_u}$$

where ALGP is the phosphorus stoichiometry of the algae and was assumed to be 0.005. The algae concentration was estimated using chl *a* data assuming the ratio between algal biomass and chl *a* is 130, which was the ratio used in model calibration (Berger et al, 2003).

The differences between the PSU estimated phosphorus stoichiometry and that estimated by DOE were small and could be attributed to slightly different approaches to averaging the data. For instance, for a few of the point sources, the phosphorus sampling data were collected on different dates than those when CBOD<sub>u</sub> were collected. When estimating phosphorus stoichiometry these data had to be either averaged or interpolated. They were generally collected on a bi-weekly or monthly basis.

**Table 1. Phosphorus stoichiometry (BODP) for CBOD compartments. The BODP calculated by PSU was listed in the last column.**

CBOD group label	Label	Old BODP	DOE estimated BODP	PSU Estimated BODP
1CBOD	Liberty	0.005	0.020	0.0204
2CBOD	Kaiser	0.005	0.002	0.0024
3CBOD	IEPC	0.005	0.002	0.0015
4CBOD	Spokane WWTP	0.005	0.016	0.0180
5CBOD	Tributaries	0.005	0.011	0.010
6CBOD	Upstream boundary	0.005	0.003	0.0036

This revision of the BODP values reflects more accurate boundary conditions for the point source dischargers than was used before. The total P from the dischargers should now be in better agreement with measured data. Model simulations described later in this report were performed using phosphorus stoichiometry BODP values estimated by the Department of Ecology.

## **Boundary File Changes**

### **Value Changed in Upstream Boundary Condition temperature file**

A temperature value in the upstream boundary condition file (statet01.npt) was changed. The value on Julian Day 288.674 (10/15/03) was changed from 13.1 to 14.1 °C. After discussing this with Ecology, this was an artifact of an earlier model alternatives simulation. The temperature was changed back to 13.1 °C, which is the measured temperature.

### **Dissolved Oxygen Groundwater Concentration**

The groundwater dissolved oxygen concentrations were set to 6.3 mg/l for branch 5 through branch 11 in the distributed tributary constituent files. The previous concentrations varied depending on the branch. The overall average of dissolved oxygen concentration calculated from well sample data was 6.74 mg/l.

### **Groundwater Temperature**

The groundwater temperature was set to 10 °C. The previously used temperatures were warmer and varied with time. This temperature compares more favorably to the average mean air temperature for Spokane during 2001 that was 8.7 °C. Generally the groundwater temperature can be assumed to be near the annual mean air temperature.

### **Groundwater Conductivity above Upriver Reservoir**

Groundwater conductivity in branches 3 and 4 were changed from 240 to 290 µmhos/cm. The original value of 240 µmhos/cm was based on the average value sampled in a number of wells. Conductivity measurements from wells near the Spokane River varied over a large range from 200 to 330 µmhos/cm, and the new value of 290 µmhos/cm was in this range.

### **Groundwater Alkalinity in branches 4 and 5**

The groundwater alkalinity in branch 4 was increased from 71.7 to 122 mg/l, and the groundwater alkalinity in branch 5 was increased from 73 to 122 mg/l. To account for the effect of alkalinity on pH, inorganic carbon concentrations were also altered in order to match pH data. The branch 4 inorganic carbon concentration was changed from 18.3 mg/l to 29.4 mg/l and the branch 5 concentration was changed from 18.23 mg/l to 29.4 mg/l. Measured alkalinity concentrations measured in nearby wells typically varied from 70 to 150 mg/l, and the value of 122 mg/l was within this range.

### **DOE Model Predictions**

Long Lake vertical profiles were plotted to illustrate the impact of DOE model changes. Figure 1 through Figure 6 show model predicted dissolved oxygen concentrations and data. The model-data dissolved oxygen comparisons for LL2 (segment 174) in Figure 4 has an additional plot showing model predictions for Julian Day 242 compared with data measured on Julian Day 241. pH model-data comparisons were shown in Figure 7

through Figure 12. Figure 13 through Figure 15 show chlorophyll *a* predictions. Figure 16 and Figure 17 show soluble reactive phosphorus predictions.

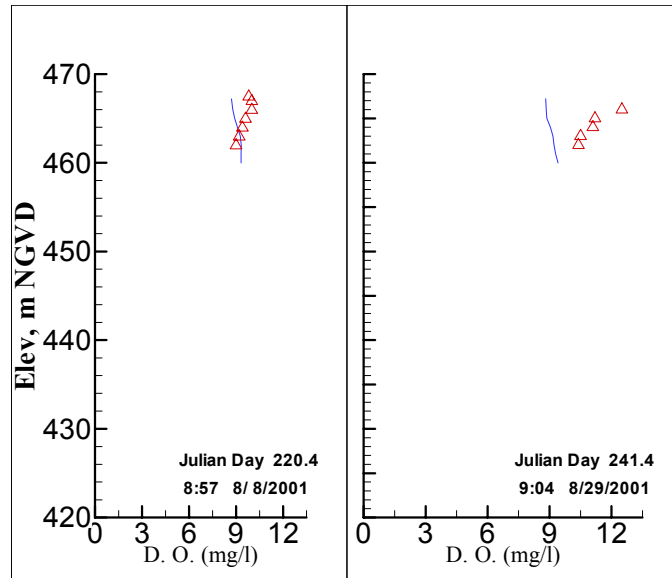
The addition of new algae groups allowed greater productivity in the late summer and fall period. The third algal group (blue-greens) in particular was more prolific in late summer resulting in better chl *a* predictions. Dissolved oxygen predictions were also better due to the increased photosynthetic oxygen production. The vertical profile error statistics for dissolved oxygen are shown in Table 2. The root mean square was improved from 1.79 mg/l to 1.30 mg/l.

Continuous dissolved oxygen data were compared with model predictions in Figure 18 and Figure 22. The change in groundwater dissolved oxygen concentration resulted in lower model predictions and improved the calibration. Figure 23 shows continuous pH data collected at Division Street compared with predictions. The increased groundwater inorganic carbon and alkalinity for branches 4 and 5 slightly improved pH predictions.

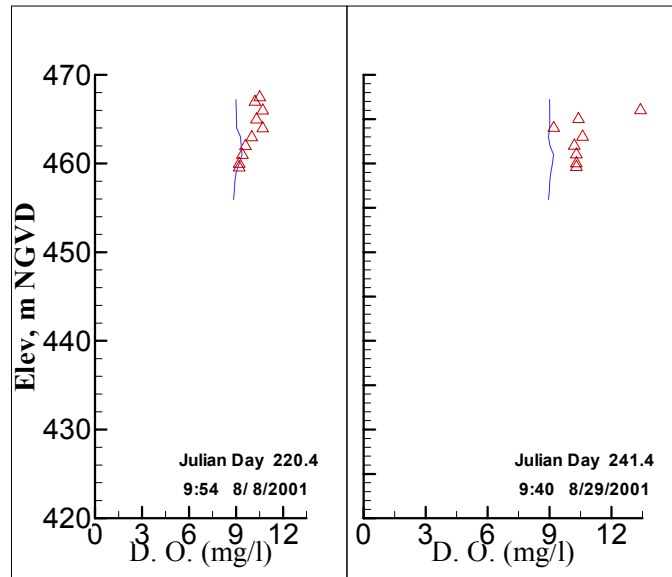
Model predictions of soluble reactive phosphorus for the Spokane River at Riverside State Park are shown in Figure 27. Predictions did not differ significantly from the original calibration. Figure 28 shows model data comparison for alkalinity measured at Riverside State Park. The improved calibration is the result of increased groundwater alkalinity concentrations in branches 4 and 5. Dissolved oxygen concentrations measured at Riverside State Park are compared with model predictions in Figure 29. Chlorophyll *a* predictions are shown in Figure 30 and CBOD ultimate predictions in Figure 31. Separating the CBOD compartment for the upstream boundary from that of the tributaries slightly lowered concentrations and improved the CBOD<sub>u</sub> calibration. Conductivity predictions are compared with data in Figure 32 through Figure 34. The change in groundwater conductivity increased model predicted conductivity and improved calibration.

**Table 2. Dissolved oxygen profile error statistics, 2001**

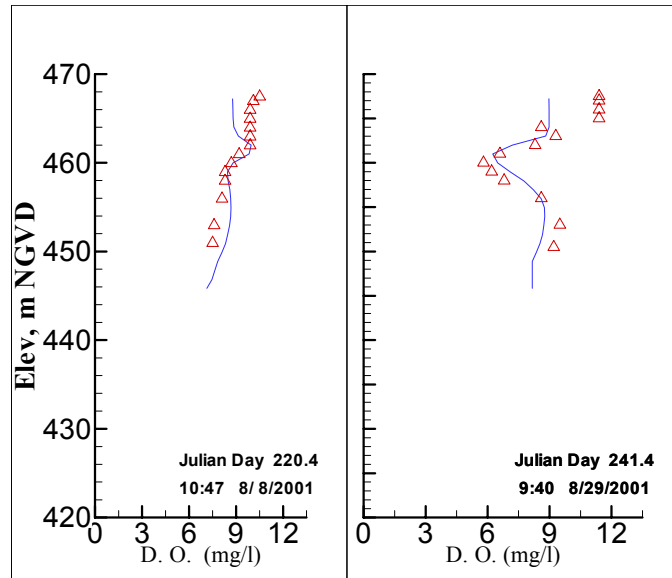
Site	n, # of data profile comparisons	DO model –data error statistics	
		AME, mg/L	RMS error, mg/L
LL0	2	0.97	1.28
LL1	2	1.24	1.51
LL2	2	1.03	1.32
LL3	2	0.85	1.05
LL4	2	1.35	1.75
LL5	2	1.62	1.85
Avg.		1.18	1.46



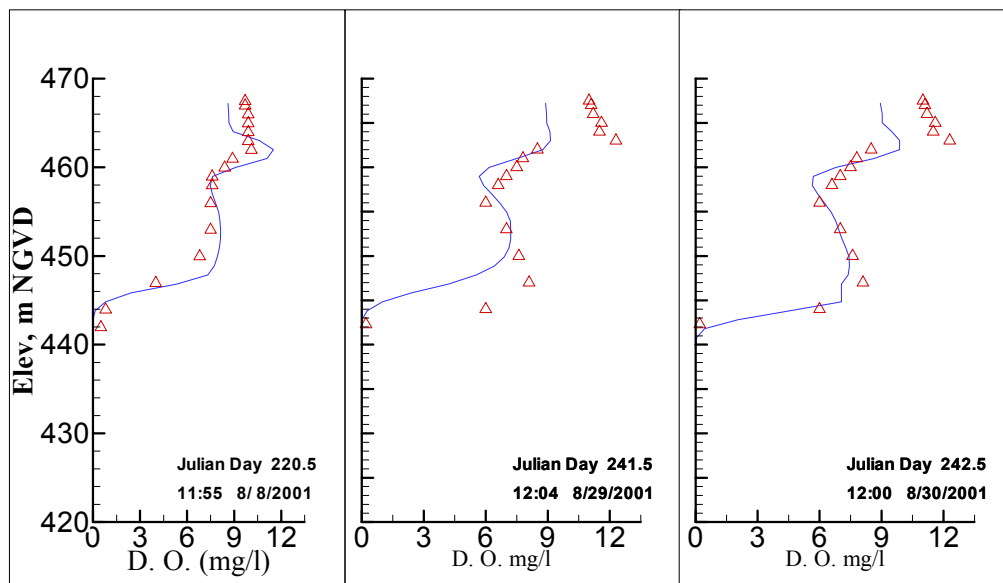
**Figure 1. Dissolved oxygen predictions and data for station LL5 (segment 157).**



**Figure 2. Dissolved oxygen predictions and data for station LL4 (segment 161).**

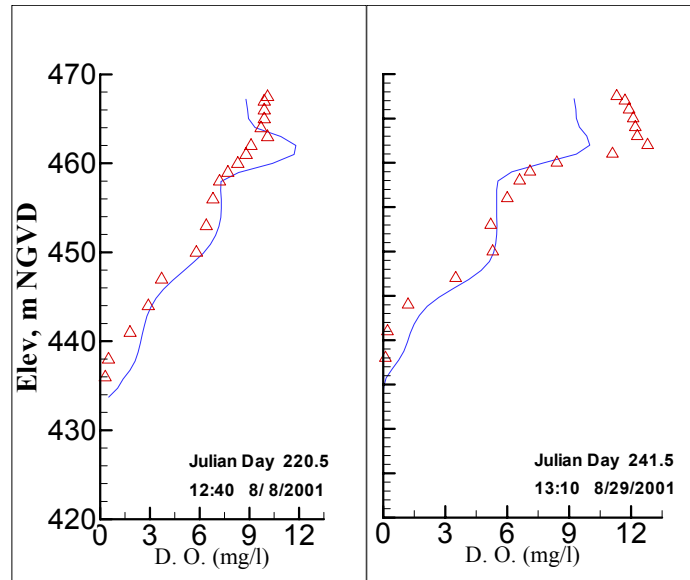


**Figure 3. Dissolved oxygen predictions and data for station LL3 (segment 168).**

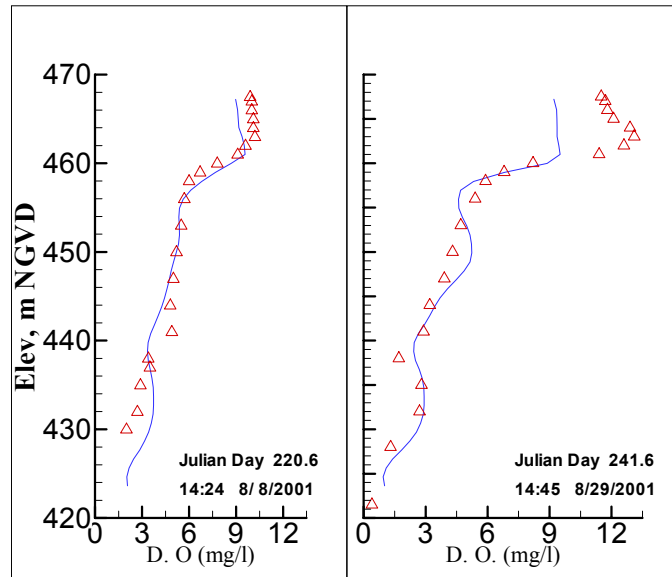


**Figure 4. Dissolved oxygen predictions and data for station LL2 (segment 174). The plot on the right compares model predictions for Julian Day 242 compared with data measured on Julian Day 241. The dynamic nature of the dissolved oxygen profile is illustrated by the difference in predictions on the two successive days.**





**Figure 5. Dissolved oxygen predictions and data for station LL1 (segment 180).**



**Figure 6. Dissolved oxygen predictions and data for station LL0 (segment 187).**

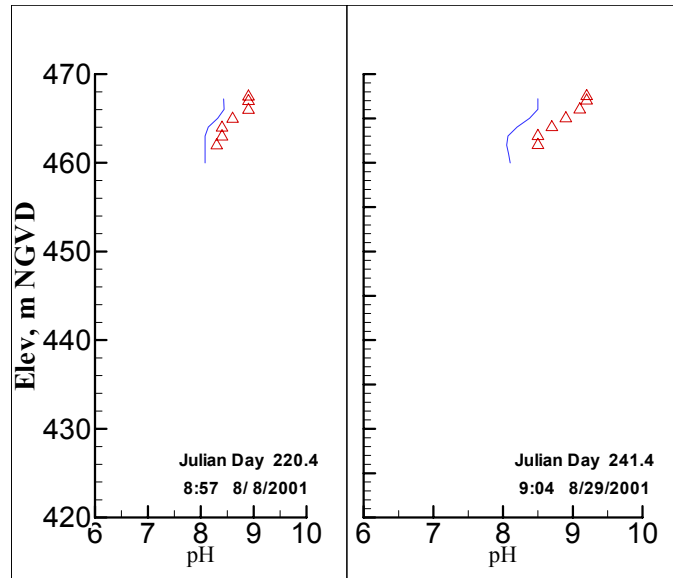


Figure 7. pH predictions and data for station LL5 (segment 157).

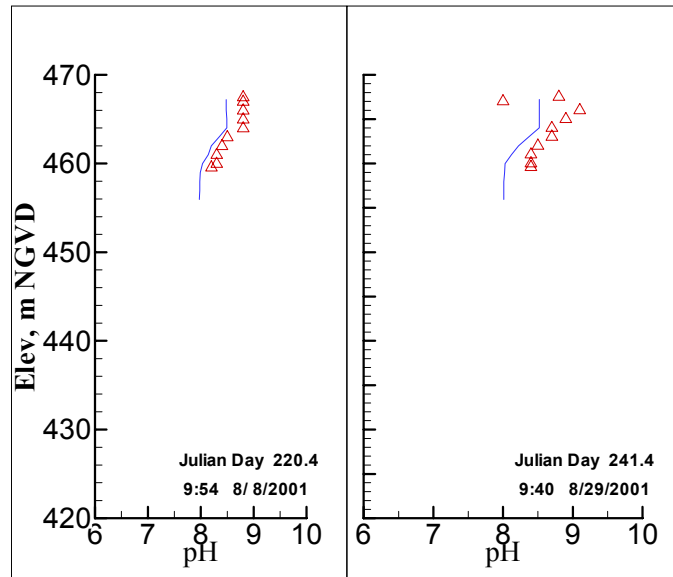


Figure 8. pH predictions and data for station LL4 (segment 161).

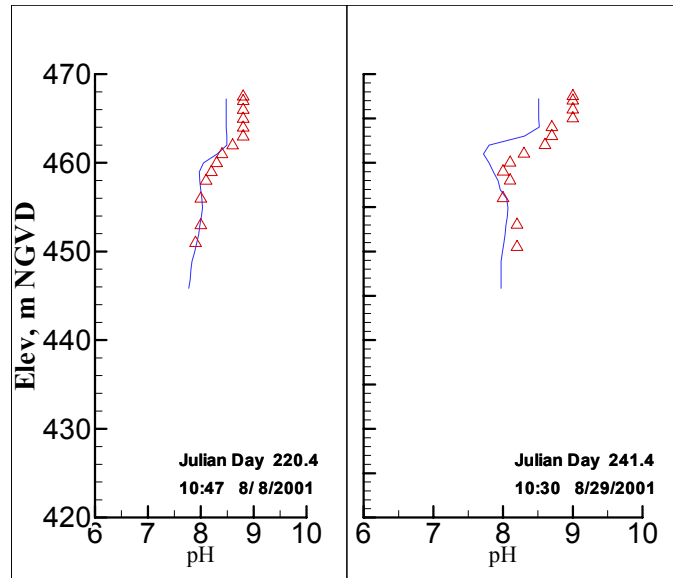


Figure 9. pH predictions and data for station LL3 (segment 168).

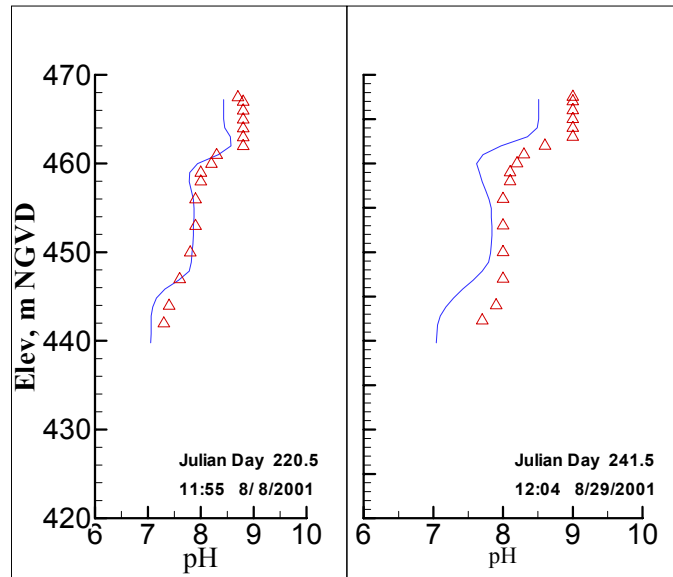


Figure 10. pH predictions and data for station LL2 (segment 174).

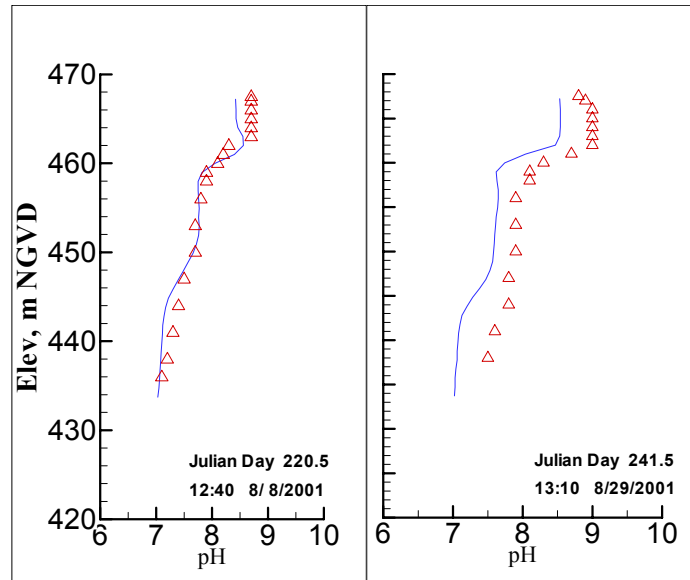


Figure 11. pH predictions and data for station LL1 (segment 180).

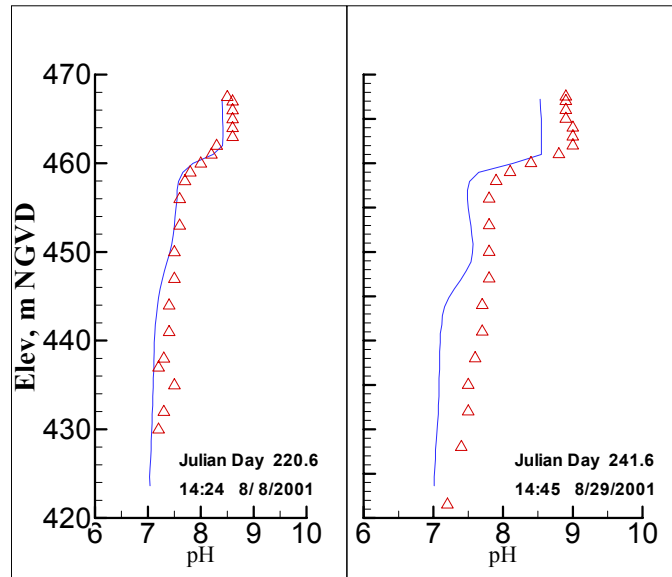


Figure 12. pH predictions and data for station LL0 (segment 187).

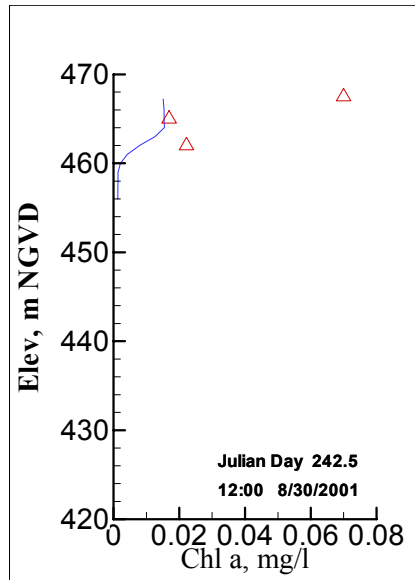


Figure 13. Chlorophyll a predictions and data for station LL4 (segment 161).

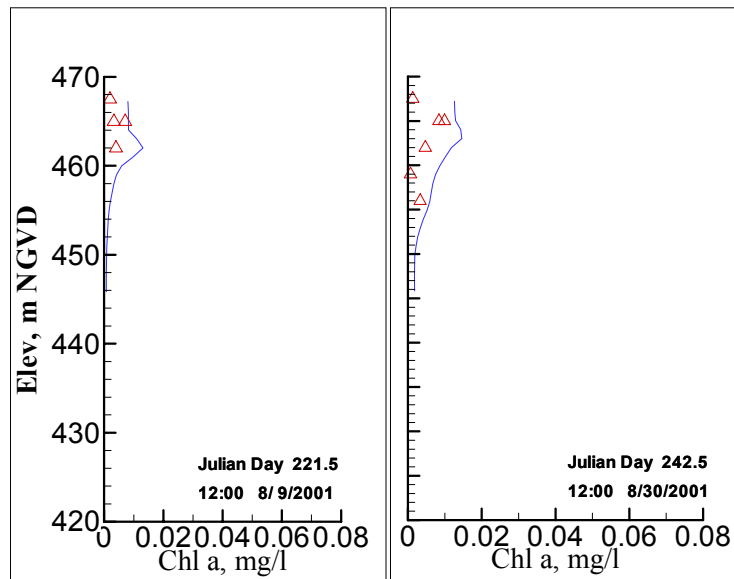


Figure 14. Chlorophyll a predictions and data for station LL3 (segment 168).

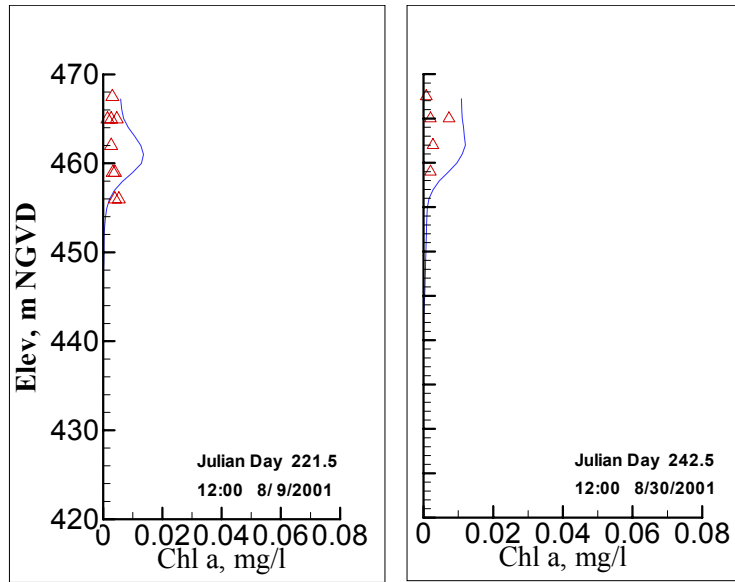


Figure 15. Chlorophyll a predictions and data for station LL1 (segment 180).

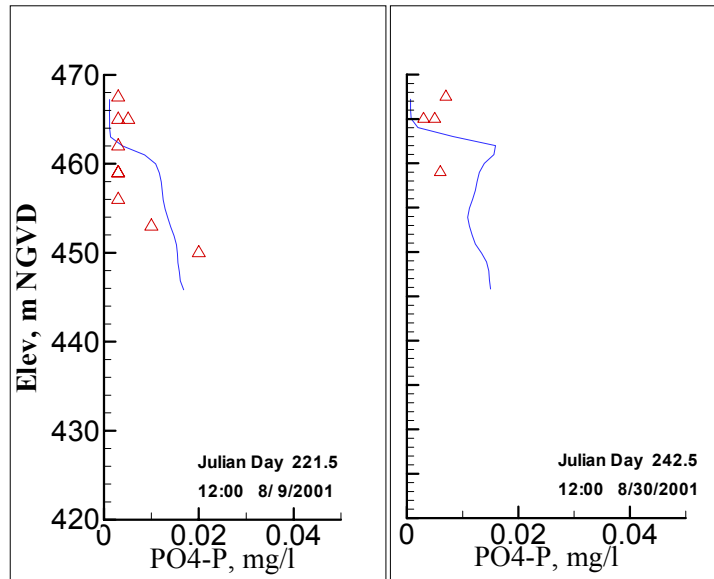


Figure 16. Soluble reactive phosphorus predictions and data for station LL3 (segment 168).

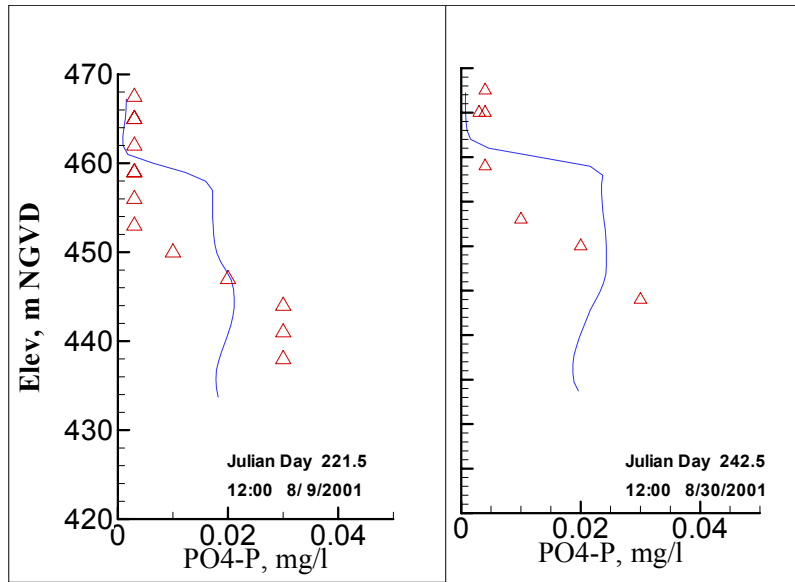


Figure 17. Soluble reactive phosphorus predictions and data for station LL1 (segment 180).

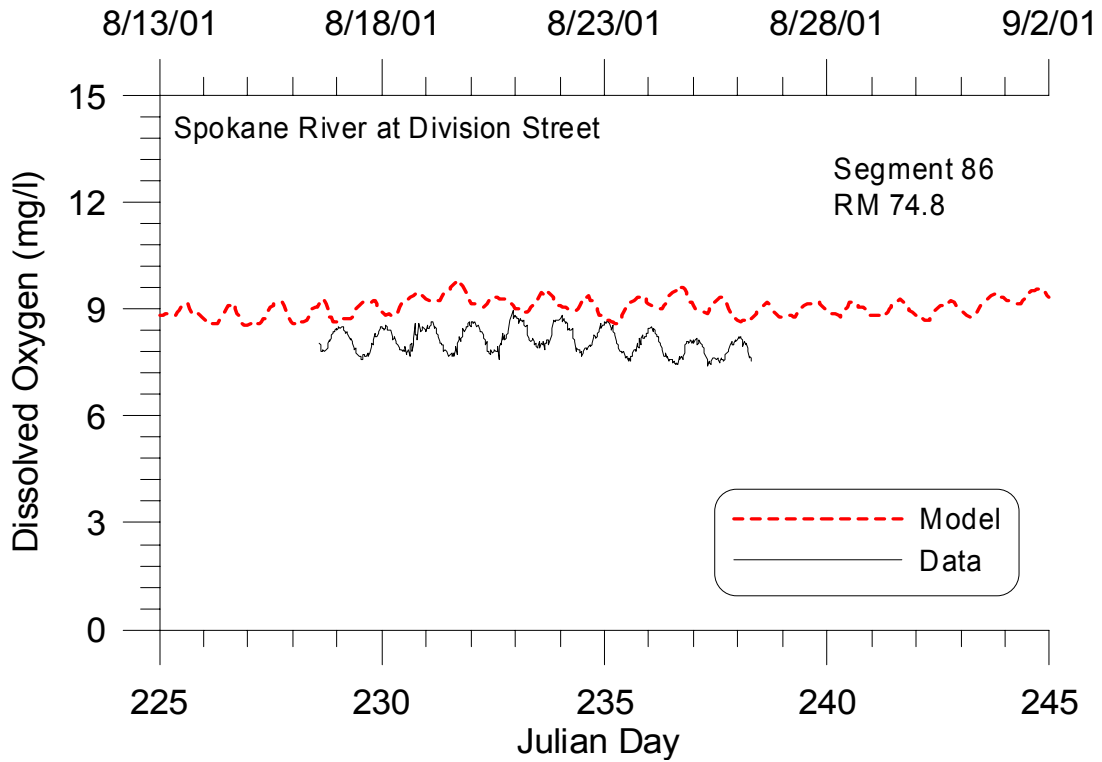


Figure 18. Dissolved oxygen predictions for Division Street (RM74.8) compared with continuous data.

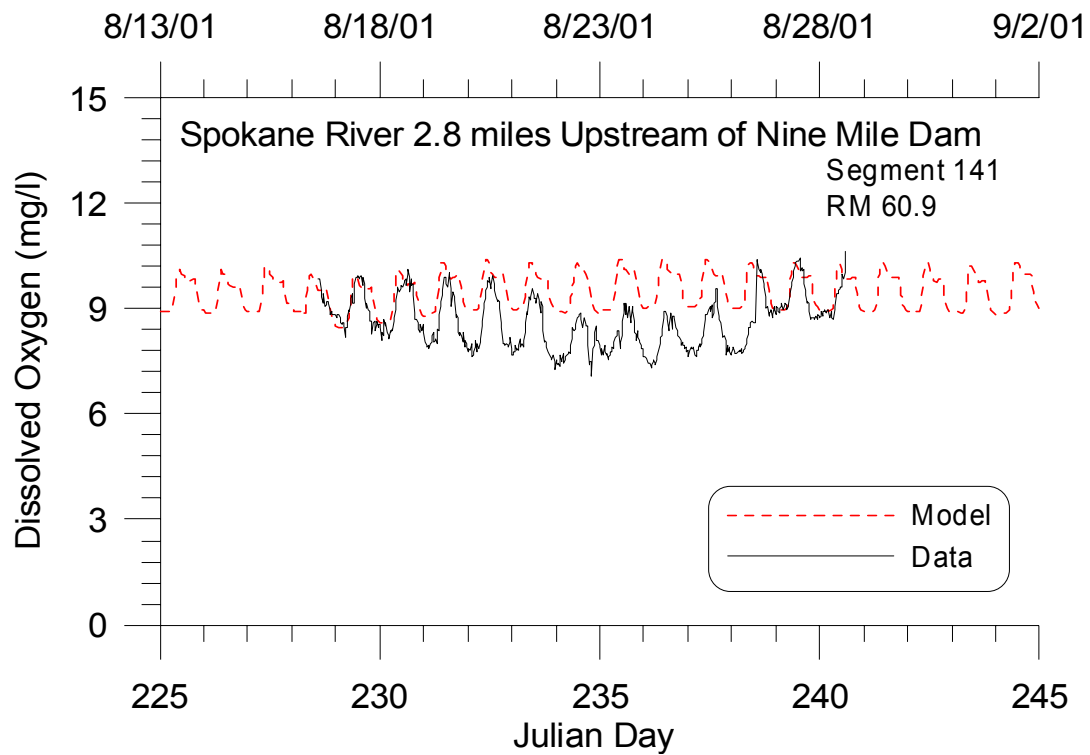


Figure 19. Dissolved oxygen predictions for RM 60.9 compared with continuous data.

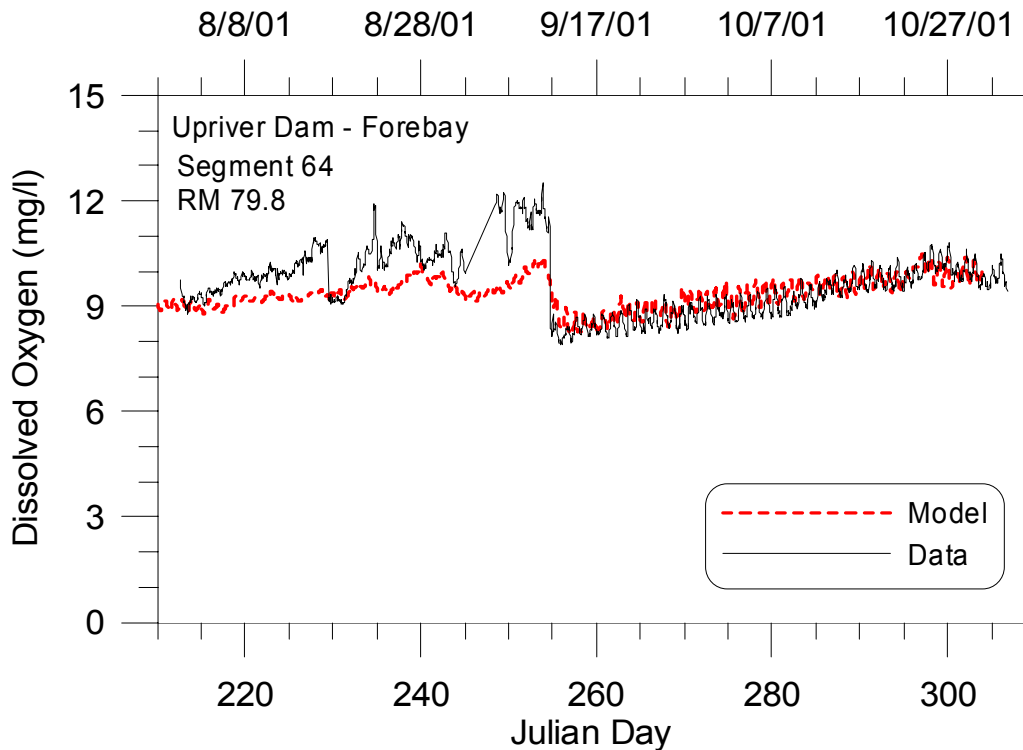


Figure 20. Dissolved oxygen predictions for the Upriver Dam Forebay (RM 79.8) compared with continuous data.



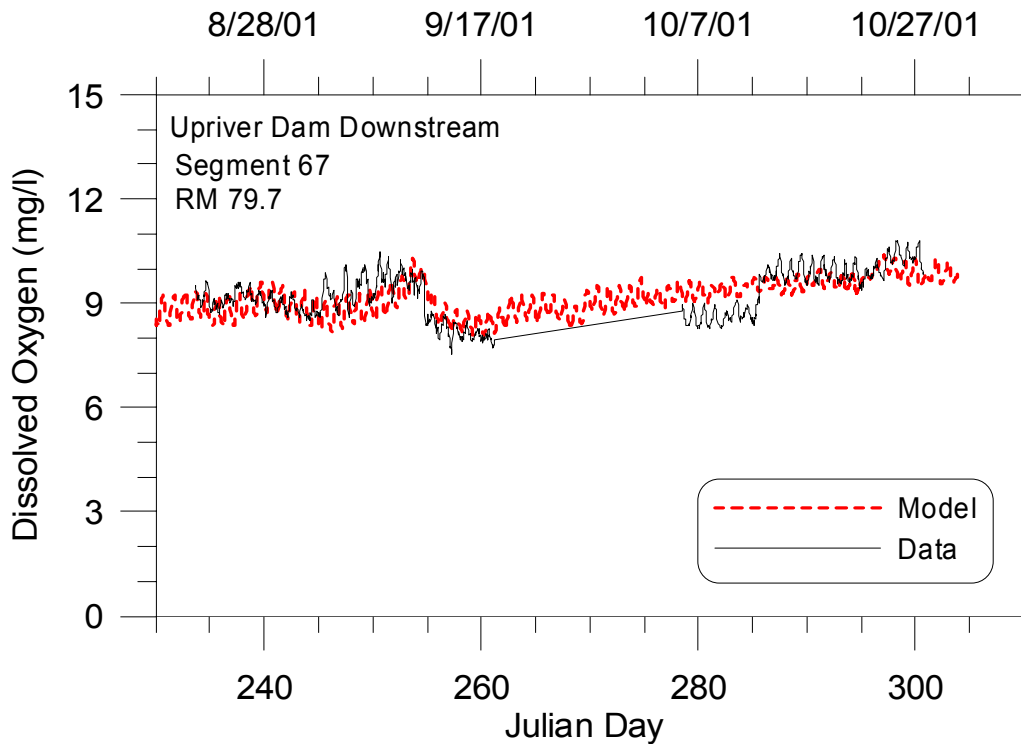


Figure 21. Dissolved oxygen predictions for downstream of Upriver Dam (RM 79.7) compared with continuous data.

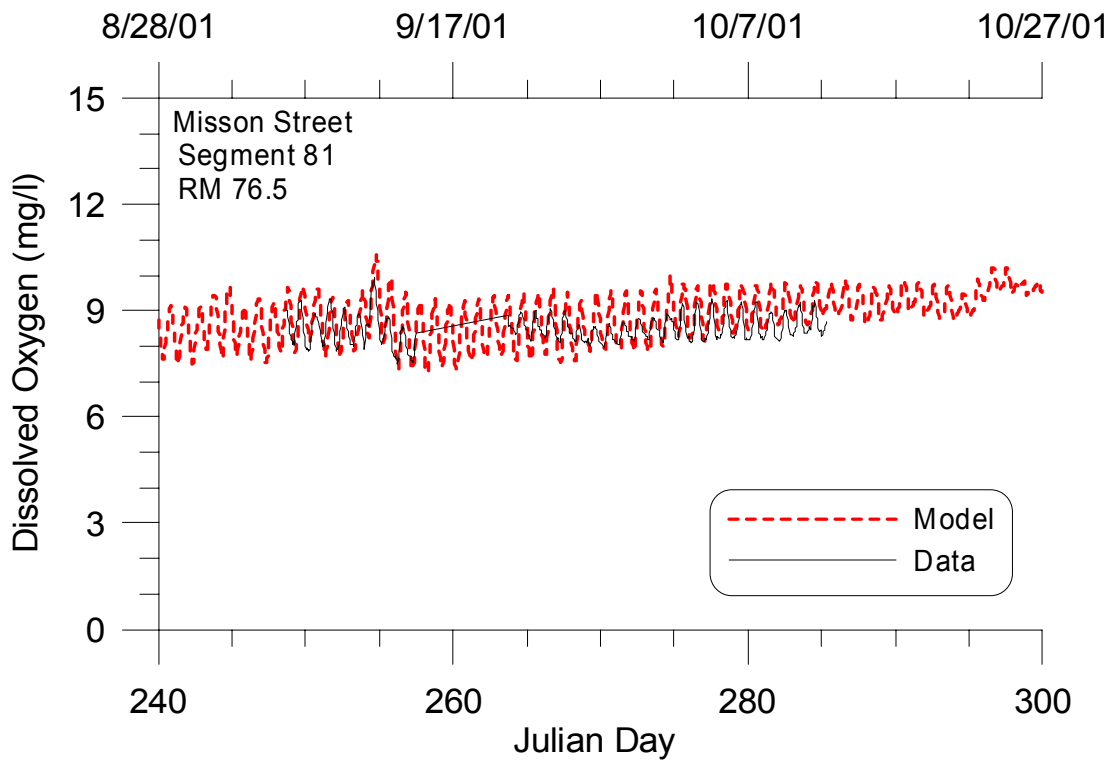


Figure 22. Dissolved oxygen predictions for Mission Street (RM 76.5) compared with continuous data.

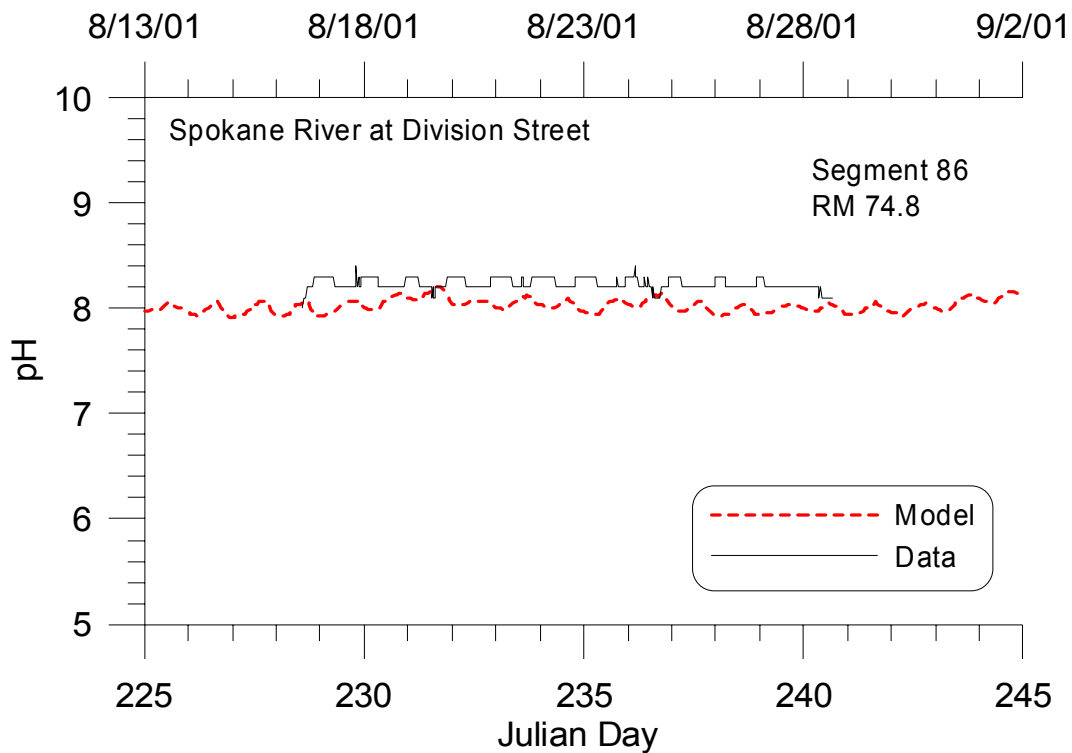


Figure 23. pH predictions for Division Street (RM74.8) compared with continuous data.

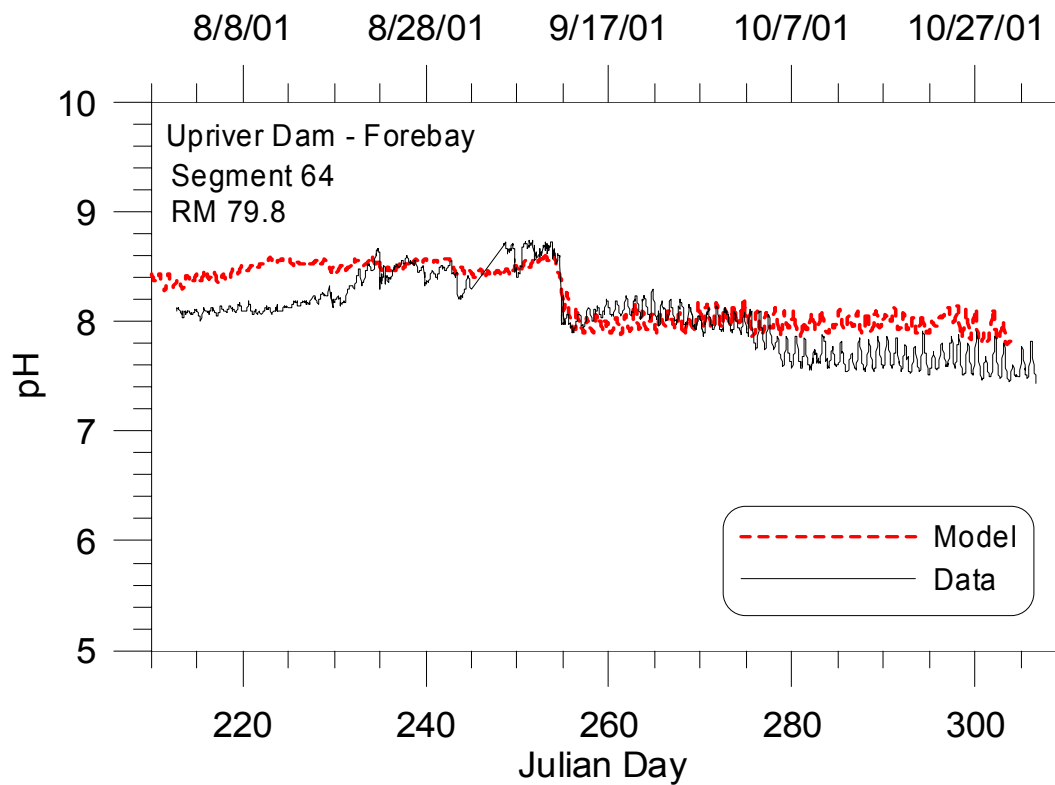


Figure 24. pH predictions for Upriver Dam Forebay (RM79.8) compared with continuous data.

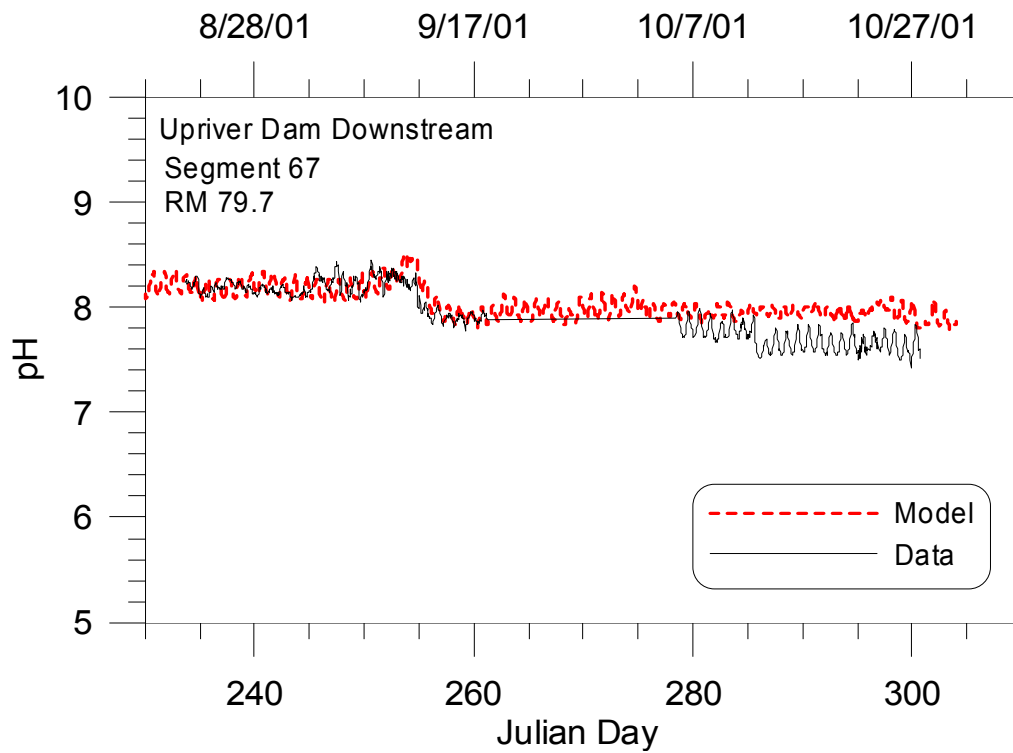


Figure 25. pH predictions downstream of Upriver Dam (RM 79.7) compared with continuous data.

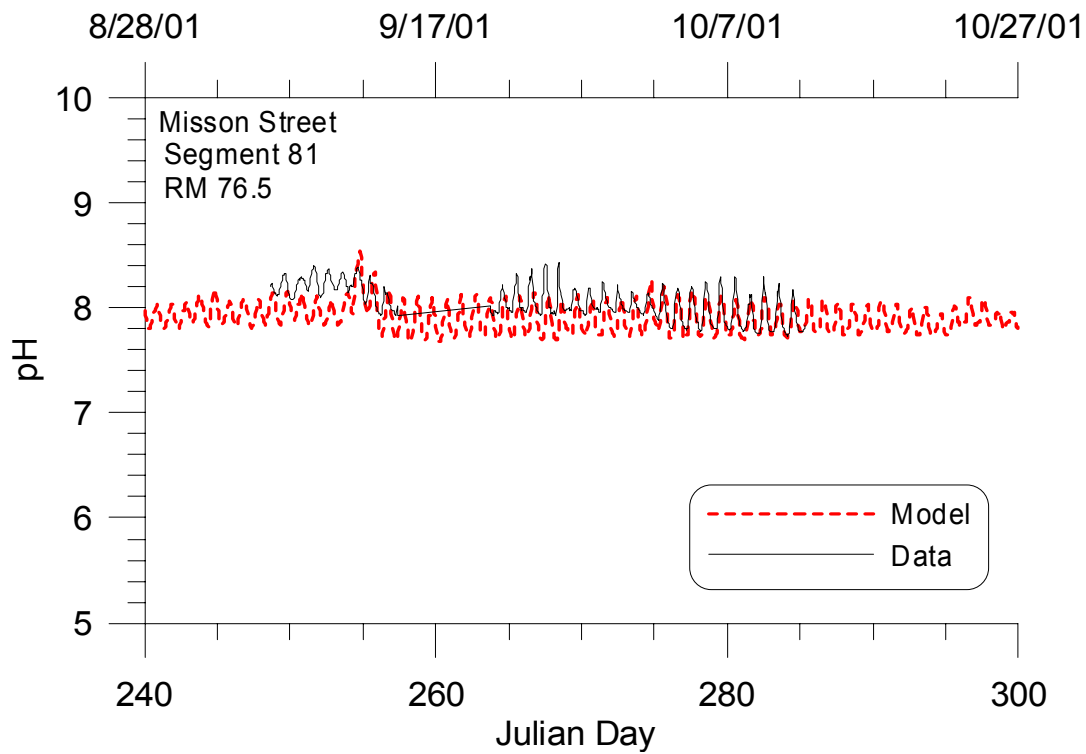


Figure 26. pH predictions for Mission Street (RM 76.5) compared with continuous data.

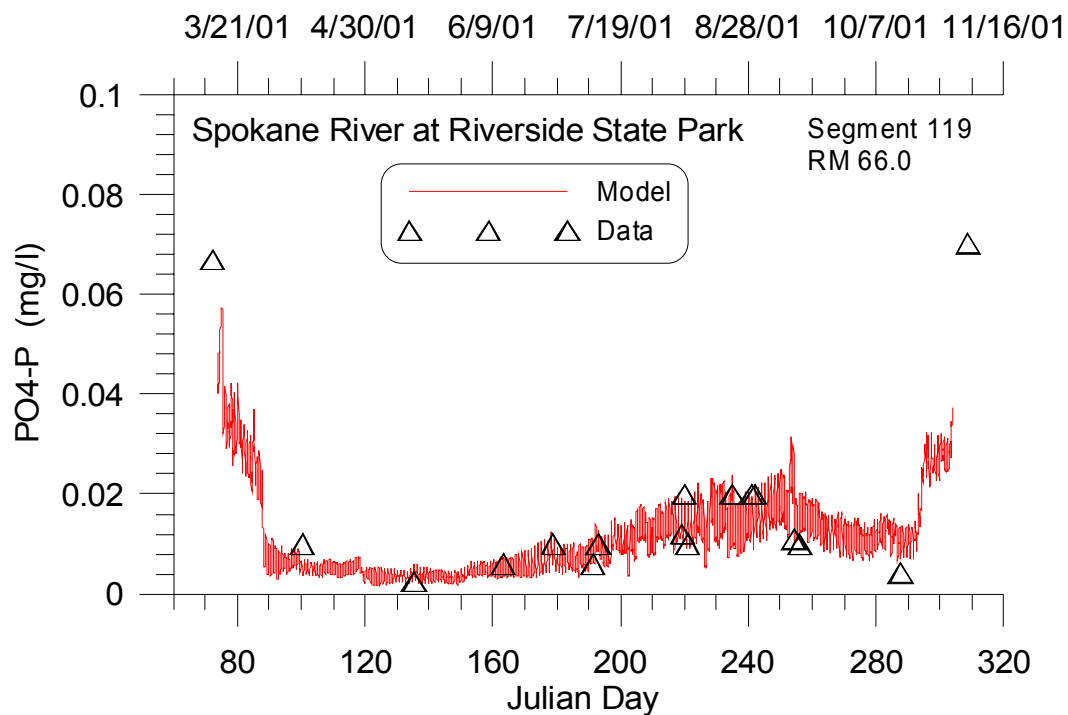


Figure 27. Soluble reactive phosphorus predictions and data for Spokane River at Riverside State Park (segment 119).

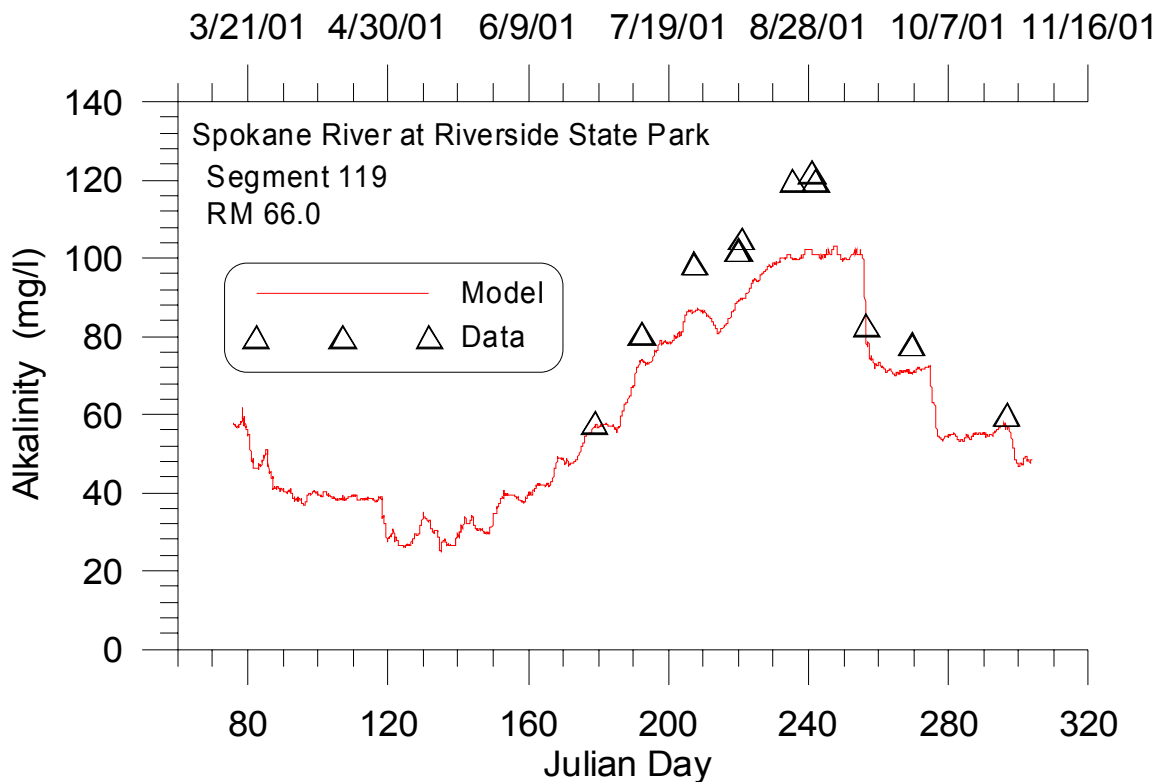


Figure 28. Alkalinity predictions and data for Spokane River at Riverside State Park (segment 119).

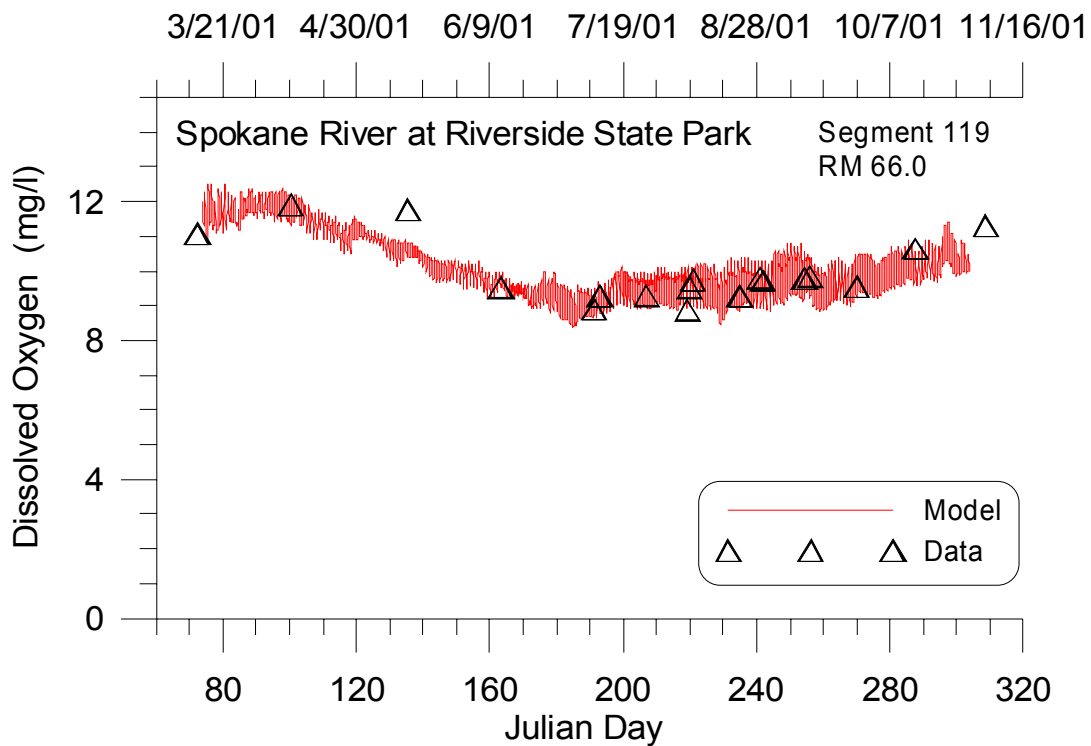


Figure 29. Dissolved Oxygen predictions and data for Spokane River at Riverside State Park (segment 119).

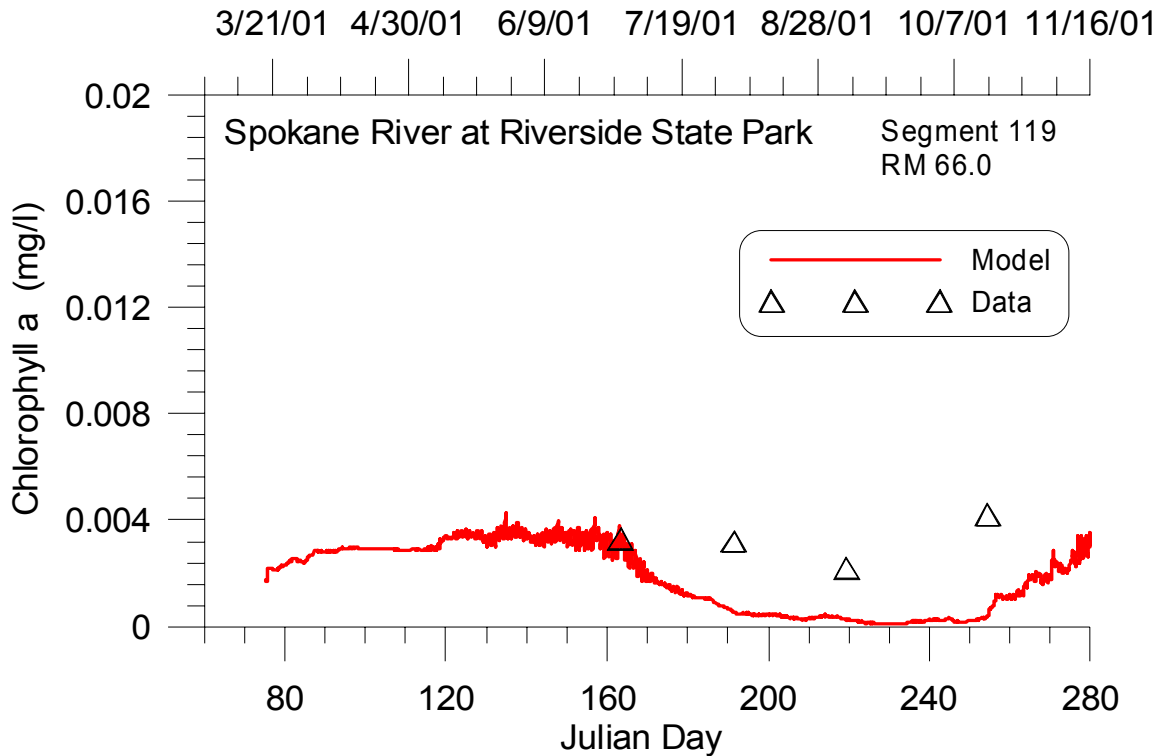


Figure 30. Chlorophyll a predictions and data for Spokane River at Riverside State Park (segment 119).

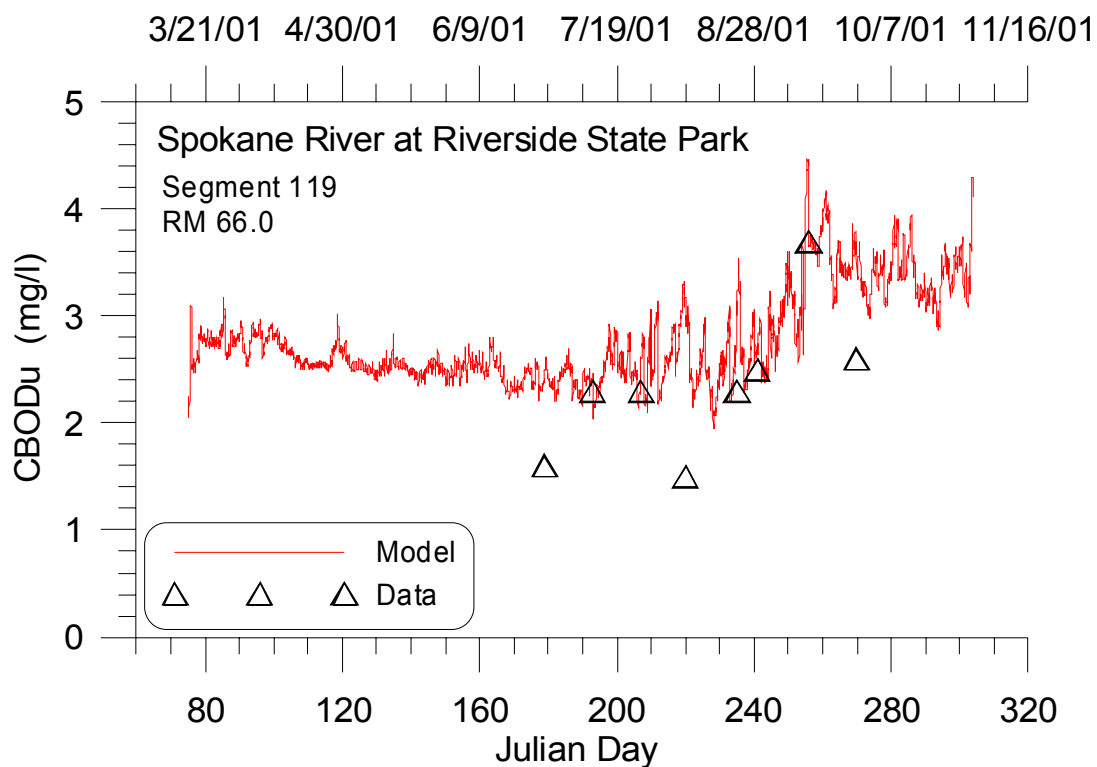


Figure 31. CBOD ultimate predictions and data for Spokane River at Riverside State Park (segment 119).

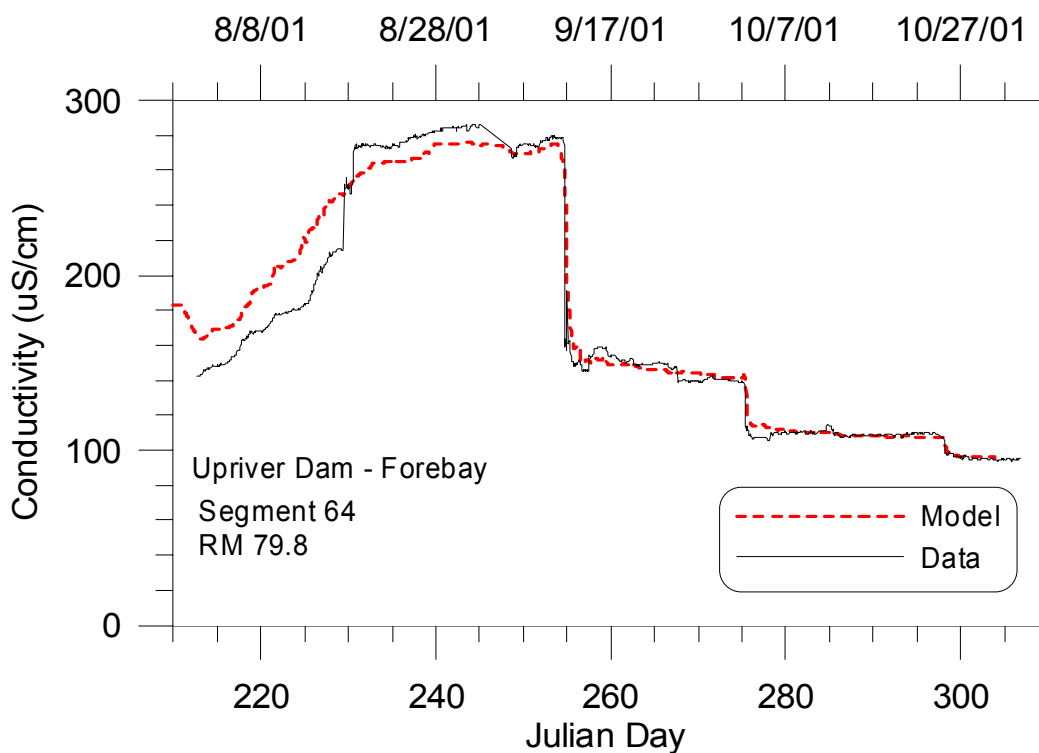


Figure 32. Conductivity predictions and data for the Upriver Dam Forebay (RM 79.8).

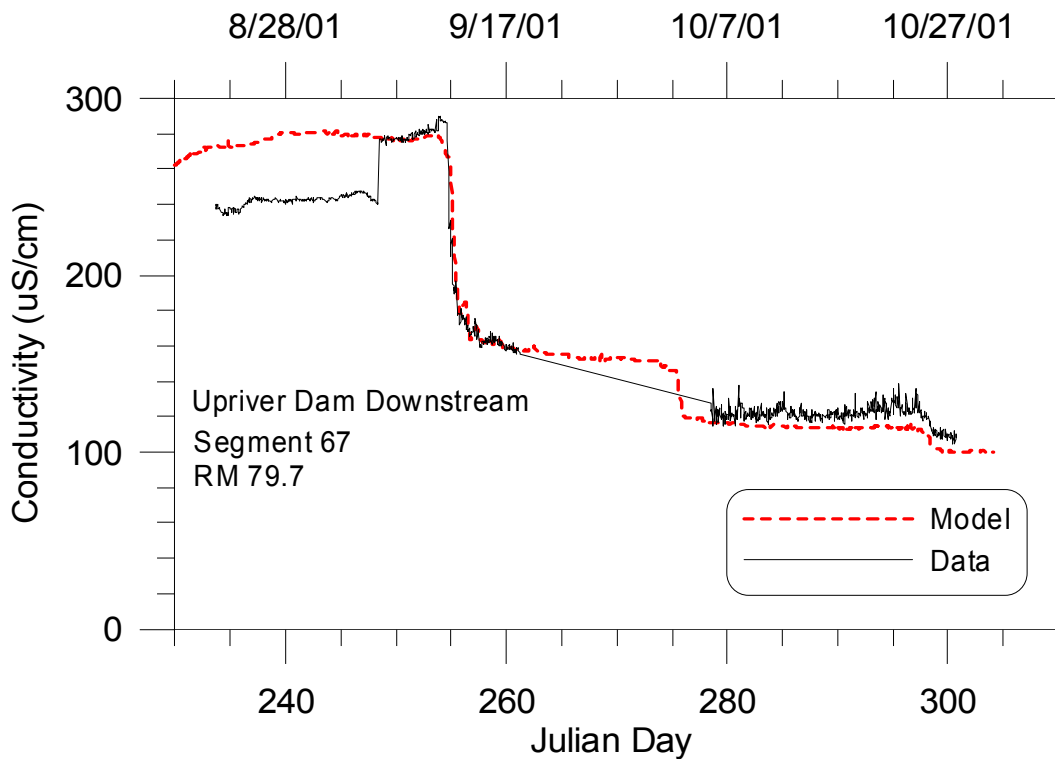


Figure 33. Conductivity predictions and data for downstream of Upriver Dam (RM 79.7).

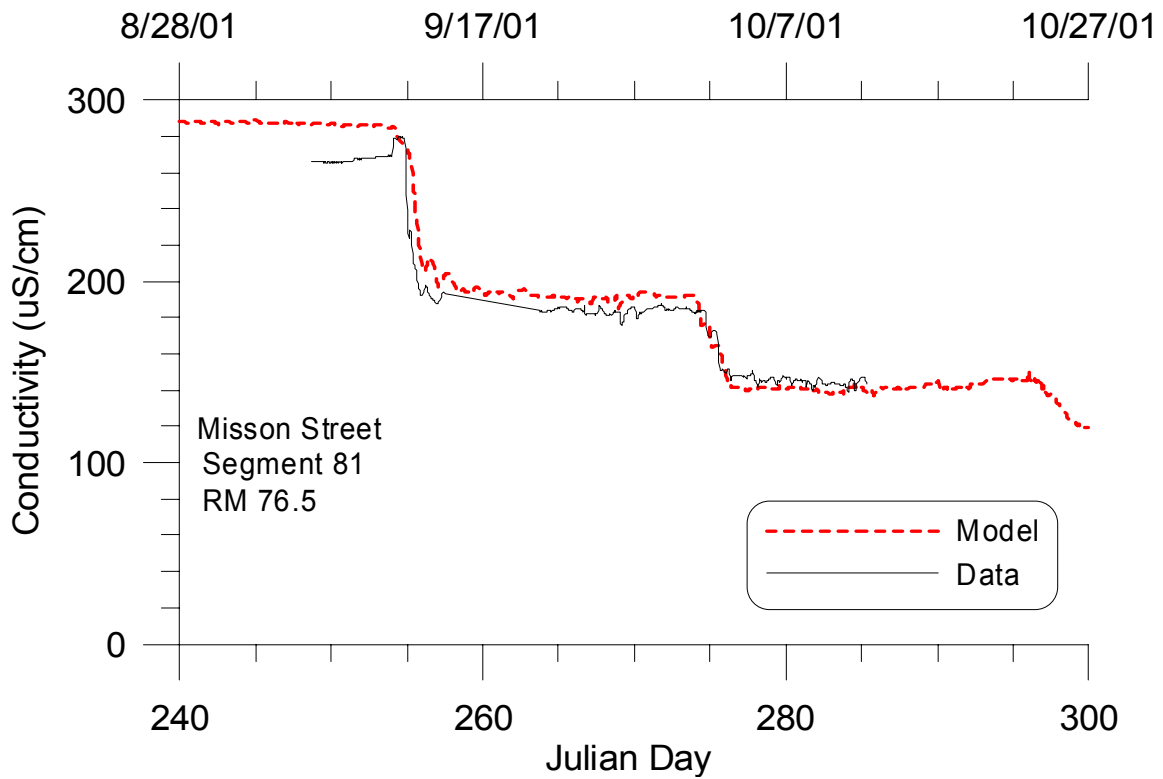


Figure 34. Conductivity predictions and data for Mission Street (RM 76.5).

## ***Additional changes by PSU***

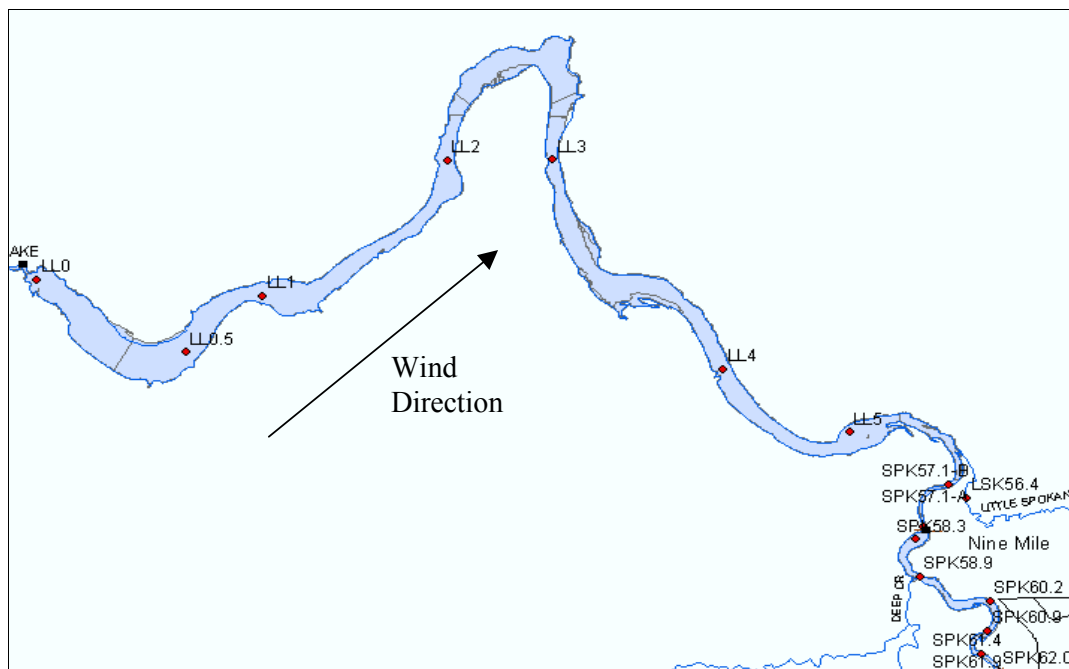
Additional model runs were performed which were designed to explore improving model predictions in Lake Spokane especially regarding the late summer blue-green bloom. Adjustments were made to the blue-green phosphorus stoichiometry, the blue-green settling rate, and the wind direction for Long Lake.

## **Inland Empire constituent file contained negative values for ISS and Chloride**

The Inland Empire point source constituent file (iepc01.npt) had some negative values for inorganic suspended solids and chloride concentrations. This was an issue that existed with the original 2001 file and has been corrected. These constituents did not impact other water quality parameters of interest.

## **Wind Direction**

Wind direction was adjusted in the Lake to help drive surface algal populations located near the surface upstream in the reservoir. Specifically, wind direction was set to an angle roughly parallel to the longitudinal axis of the western half of the reservoir (Figure 35). This set up a surface current flowing upstream. Because wind direction data originally used by the model was collected at the Spokane Airport and not at the reservoir, it was felt this was a reasonable assumption. Wind direction in reservoirs can be dependent on the adjacent topography and thus is very localized. This is obviously an area where on-site data collection could help us understand wind-driven currents in Long Lake.



**Figure 35. Orientation of wind direction in Spokane Lake.**



### **Blue-green algal phosphorus stoichiometry**

An adjustment was made to the phosphorus stoichiometry (ALGP) of the blue green algae group (algal group 3). The value of ALGP was changed from 0.005 to 0.0025.

### **Blue-green algal settling rate**

To simulate the rising phenomena of blue-greens in Lake Spokane, a negative settling rate was applied. CE-QUAL-W2 can accept a negative settling rate for algae implying that the algae are ‘floaters’ and adjust their internal buoyancy to achieve positive buoyancy. A negative settling rate of  $-2$  m/d resulted in larger accumulations of algae near the surface and near the upper end of the reservoir closer to the plunge point of the incoming Spokane River. In another simulation, a very small settling rate of  $0.01$  m/d, which was used by Ecology, was investigated as a comparison to the negative settling velocity.

### **Sediment release rate of phosphorus**

The sediment release rate of phosphorus under anaerobic conditions (PO4R) was changed from a value  $0.001$  to  $0.01$ . The former value of  $0.001$  was considered too low based on literature values. The release rate is specified as a fraction of SOD demand.

### ***Model Results***

Simulations were run for the 2001 model year. The only difference between the simulations was the blue-green algal settling rate. The settling rate was set to  $-2$  m/d for Run 1 and  $+0.01$  m/d for Run 2.

Figure 36 to Figure 38 compare contour plots of blue-green algal biomass for the two simulations on successive dates. The negative settling rate simulation predicted higher biomass near the plunge point at the upstream end of the reservoir.

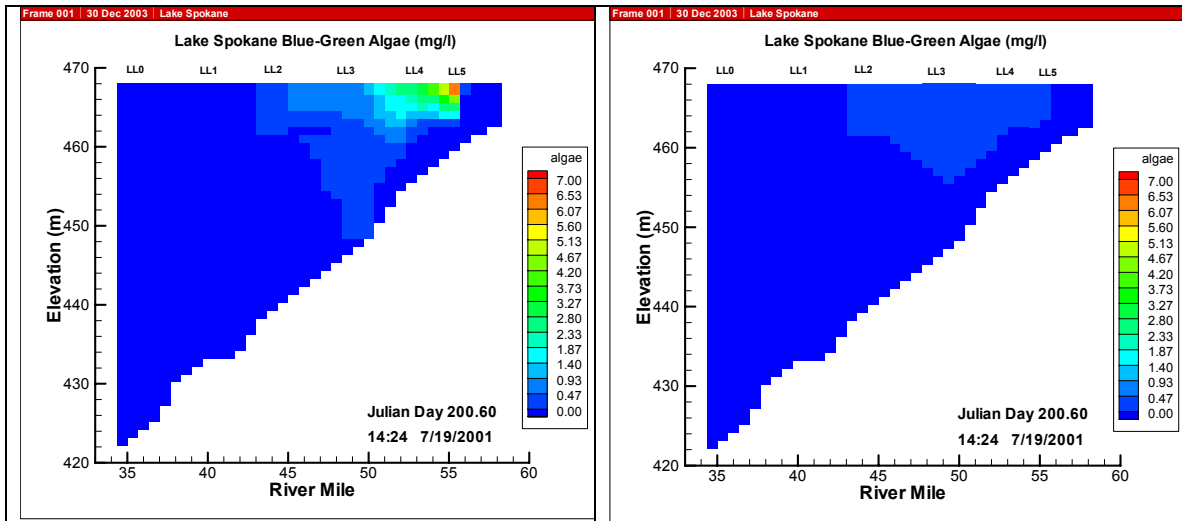


Figure 36. Lake Spokane algae predictions on 7/19/01 with blue-green algae settling rate of -2 m/d (Run 1) on the left compared to a settling rate of 0.01 m/d (Run 2) on the right.

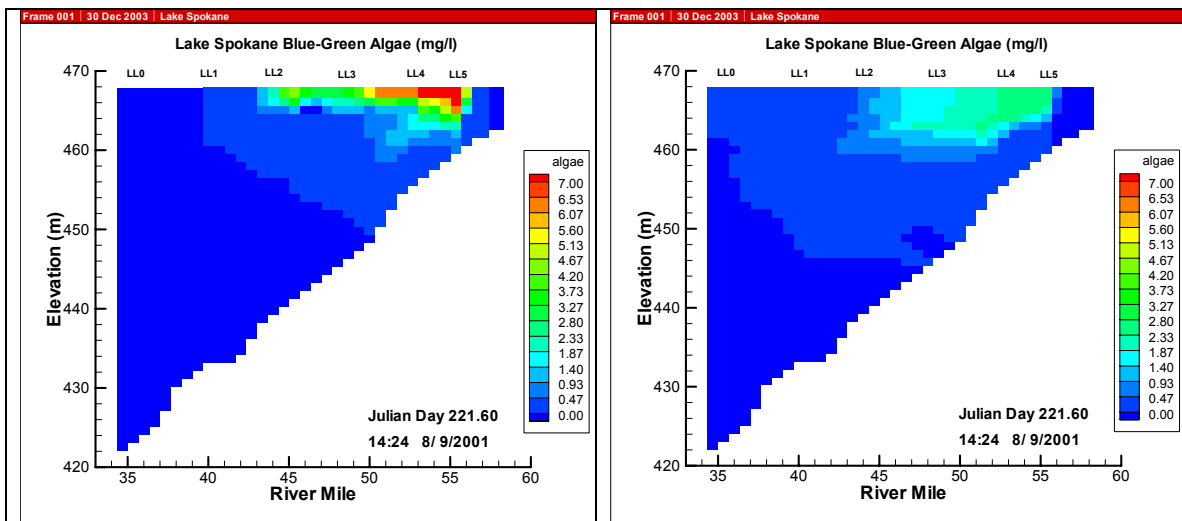


Figure 37. Lake Spokane algae predictions on 8/9/01 with blue-green algae settling rate of -2 m/d (left) compared to a settling rate of 0.01 m/d (right).

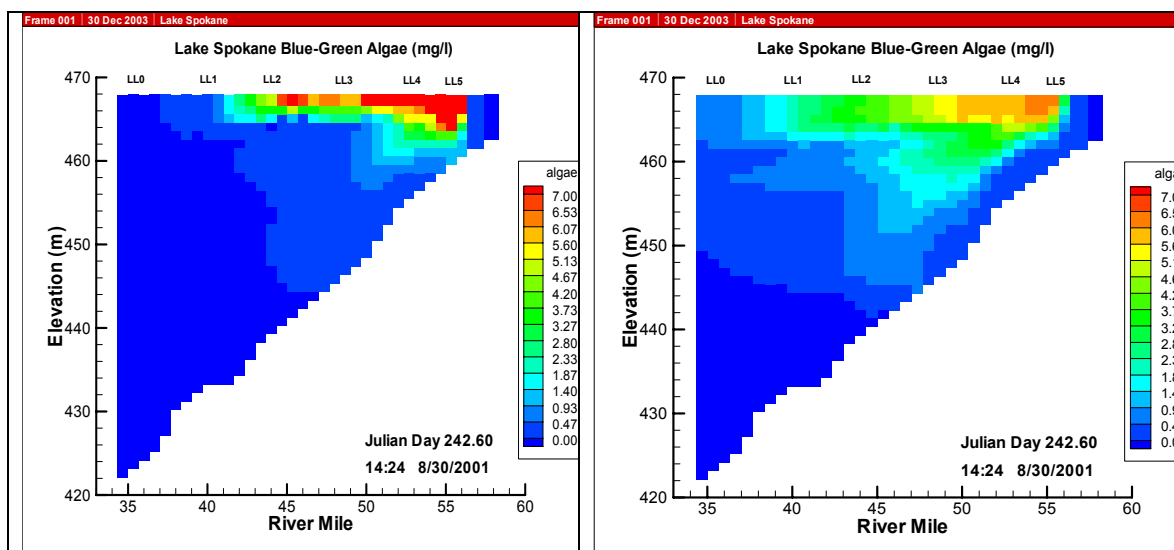


Figure 38. Lake Spokane algae predictions on 8/30/01 with blue-green algae settling rate of -2 m/d (left) compared to a settling rate of 0.01 m/d (right).

## Calibration Results

In addition to examining the dynamic of the blue-green blooms, vertical profile model-data comparisons were also performed as a check on the model calibration. These model-data comparisons are shown below. Run 1 incorporated a blue-green algae settling rate of -2 m/d. Run 2 used a positive settling rate of 0.01 m/d.

### Run 1 - Blue green settling rate of -2 m/d

#### Long Lake

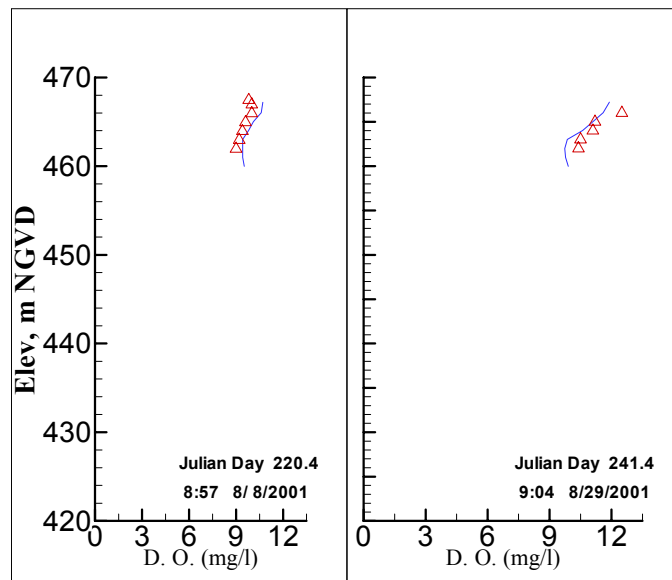
A settling rate of -2 m/d for the blue-green algae resulted in greater algal concentrations downstream of the plunge point for reservoir inflows. Algae floated to the surface and moved upstream in a surface current induced by the wind. Model predicted dissolved oxygen concentrations are plotted with data in Figure 39 through Figure 44. Dissolved oxygen error statistics are listed in Table 3. The greater predicted algal biomass improved dissolved oxygen predictions at sampling stations LL2, LL3, LL4 and LL5. pH predictions are shown in Figure 45 through Figure 50. The higher upstream algae biomass is reflected in the chl *a* predictions shown in Figure 51 through Figure 53. The model correctly predicted higher chl *a* concentrations at LL4 and LL3 and lesser concentrations downstream at LL1. Soluble reactive phosphorus predictions compared to data are shown in Figure 54 and Figure 55. Consistent with the data, lower concentrations are predicted in the epilimnion and higher concentrations in the hypolimnion. Total phosphorus predictions are plotted in Figure 56 and Figure 57. The vertical temperature profiles are compared with data in Figure 58 through Figure 63. The change in wind direction only slightly affected the vertical temperature profiles.

### Spokane River

Dissolved oxygen concentrations measured in the river were plotted with data in Figure 64 and Figure 65. A comparison between model predicted pH and data in the Spokane River is shown in Figure 66.

**Table 3. Run 1 dissolved oxygen profile error statistics, 2001**

Site	n, # of data profile comparisons	DO model –data error statistics	
		AME, mg/L	RMS error, mg/L
LL0	2	0.85	1.09
LL1	2	1.16	1.34
LL2	2	0.93	1.17
LL3	2	0.74	0.99
LL4	2	0.66	0.80
LL5	2	0.62	0.71
Avg.		0.83	1.02



**Figure 39. Run 1 dissolved oxygen predictions and data for station LL5 (segment 157).**

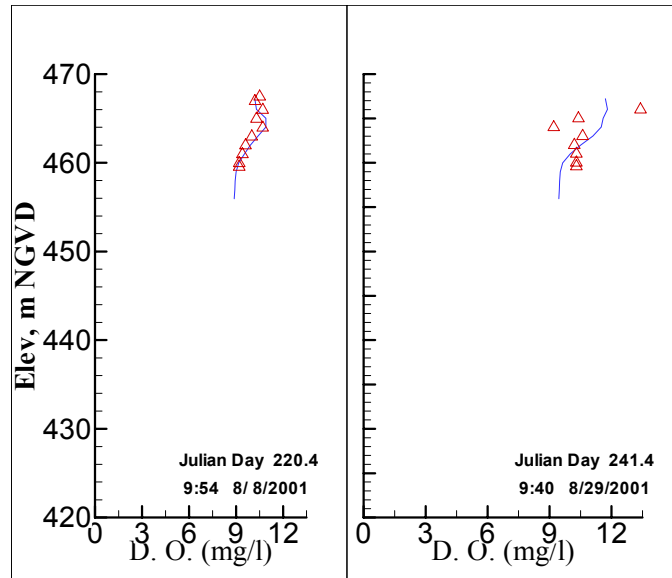


Figure 40. Run 1 dissolved oxygen predictions and data for station LL4 (segment 161).

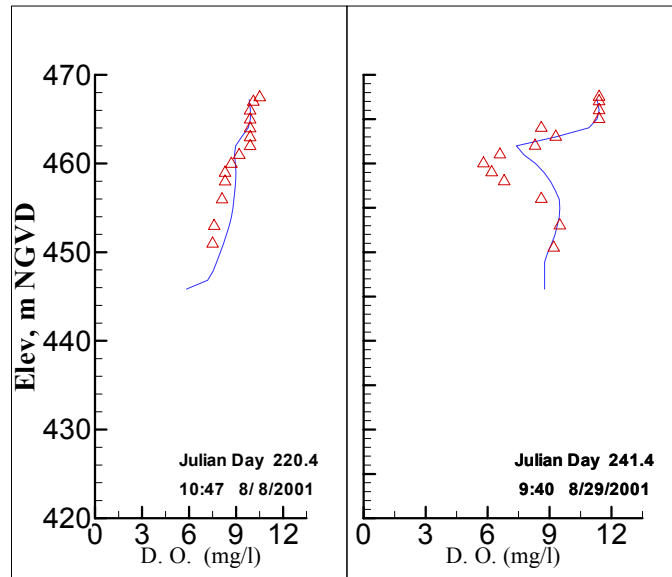


Figure 41. Run 1 dissolved oxygen predictions and data for station LL3 (segment 168).

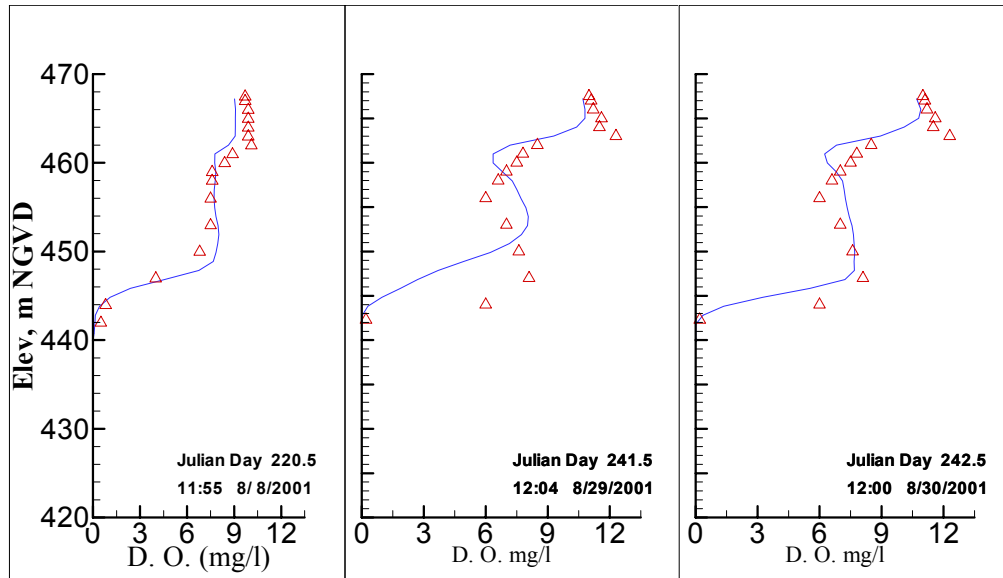


Figure 42. Run 1 dissolved oxygen predictions and data for station LL2 (segment 174). The frame on the right compares model predictions for Julian Day 242 with data collected on Julian Day 241.

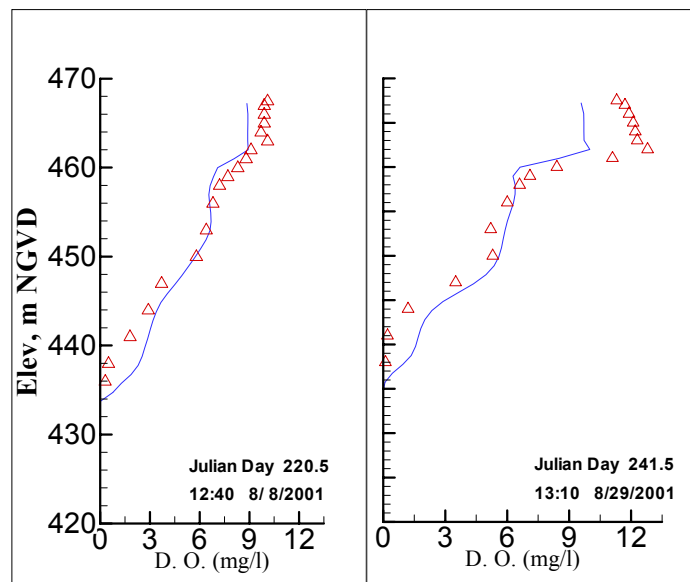


Figure 43. Run 1 dissolved oxygen predictions and data for station LL1 (segment 180).

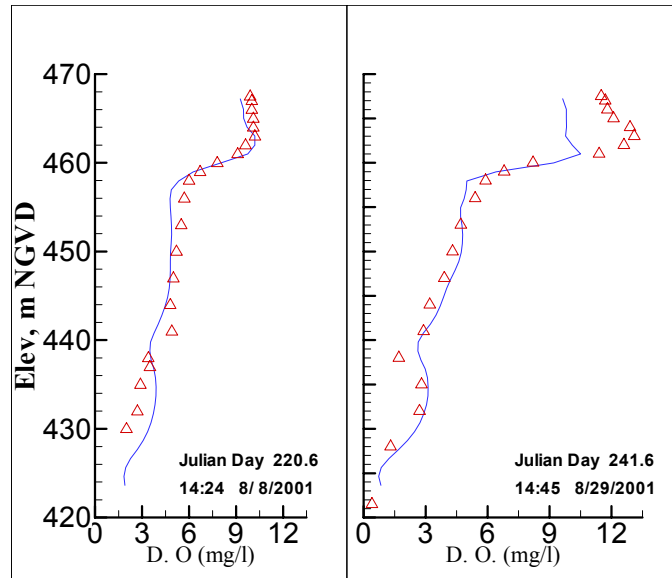


Figure 44. Run 1 dissolved oxygen predictions and data for station LL0 (segment 187).

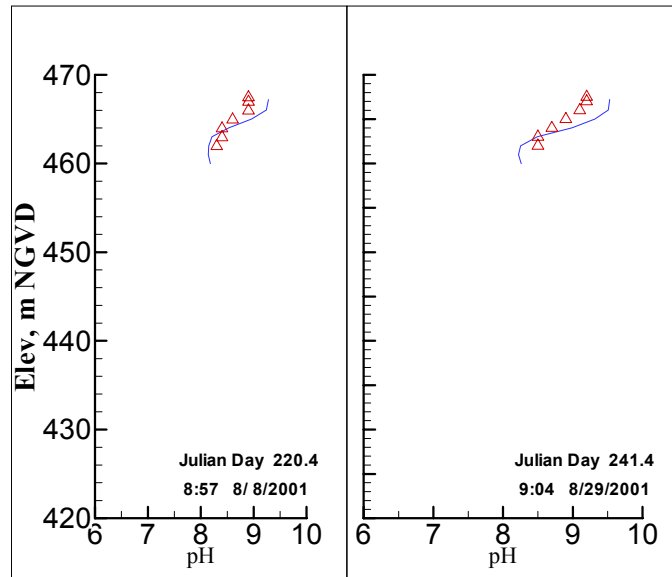


Figure 45. Run 1 pH predictions and data for station LL5 (segment 157).

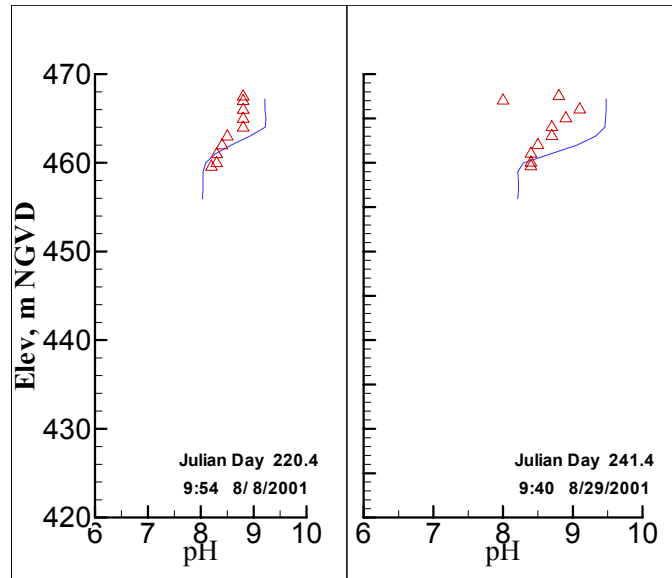


Figure 46. Run 1 pH predictions and data for station LL4 (segment 161).

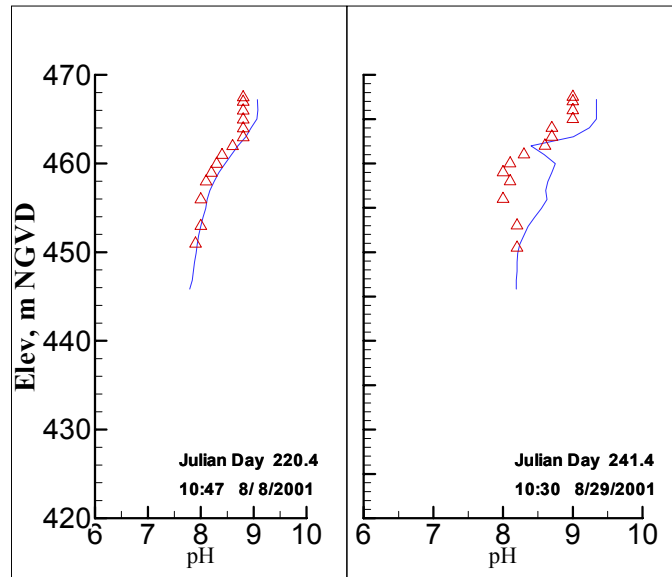


Figure 47. Run 1 pH predictions and data for station LL3 (segment 168).



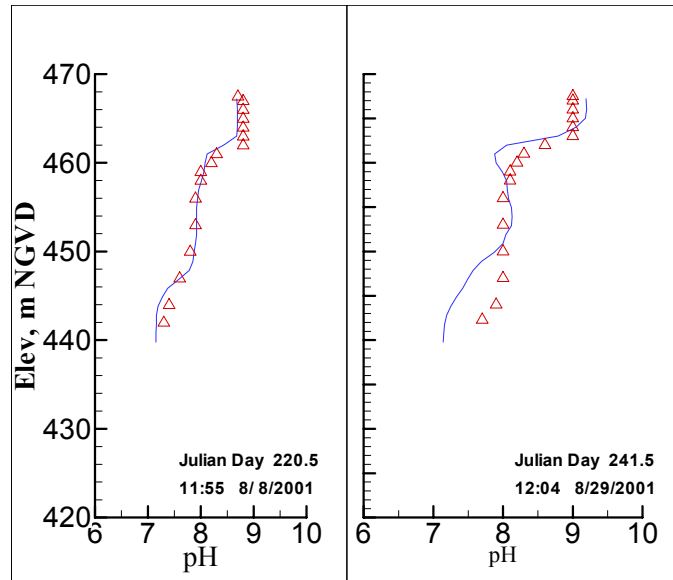


Figure 48. Run 1 pH predictions and data for station LL2 (segment 174).

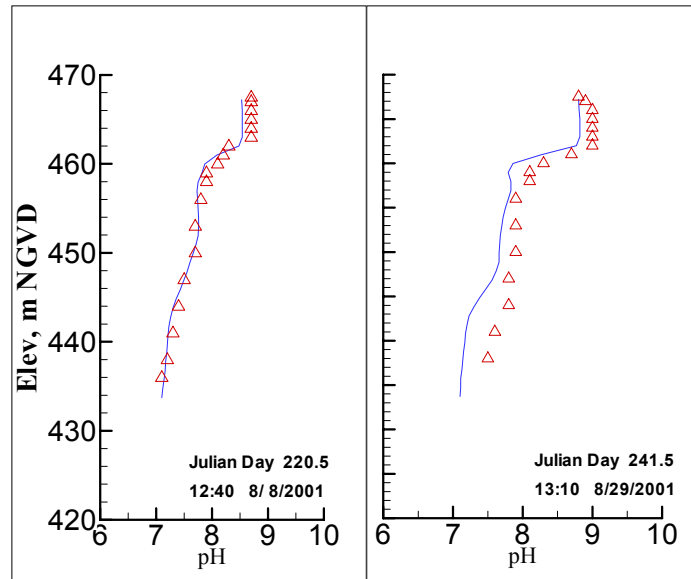


Figure 49. Run 1 pH predictions and data for station LL1 (segment 180).

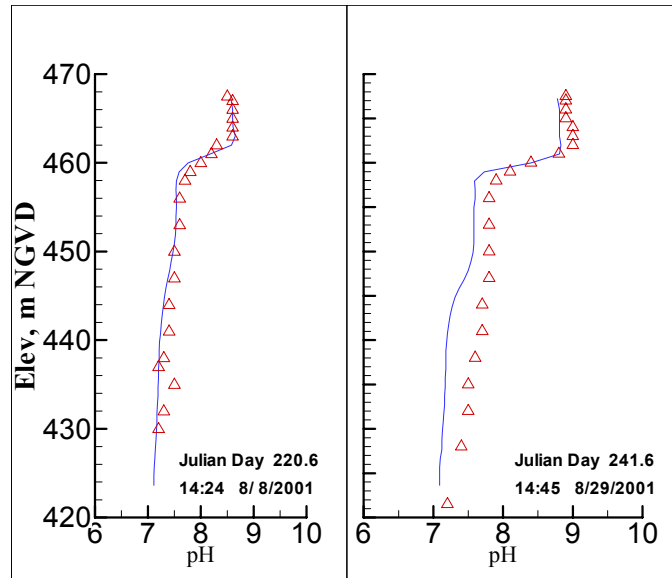


Figure 50. Run 1 pH predictions and data for station LL0 (segment 187).

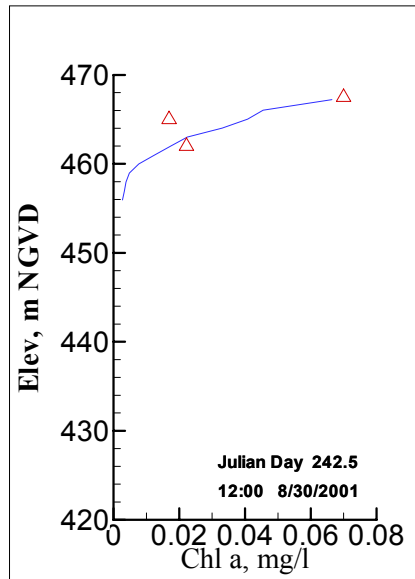


Figure 51. Run 1 chlorophyll a predictions and data for station LL4 (segment 161).

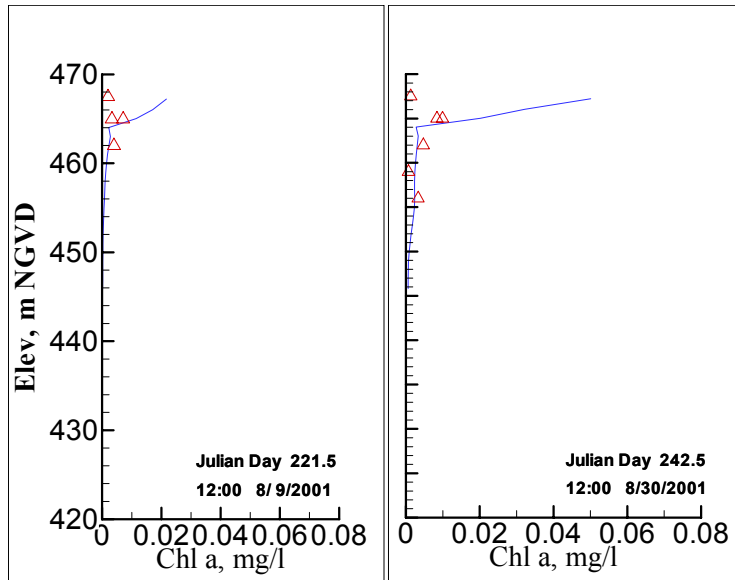


Figure 52. Run 1 chlorophyll a predictions and data for station LL3 (segment 168).

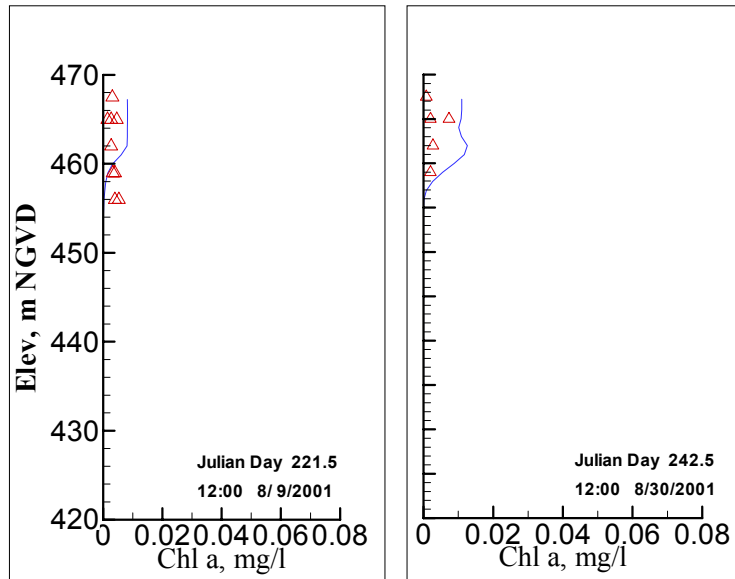


Figure 53. Run 1 chlorophyll a predictions and data for station LL1 (segment 180).

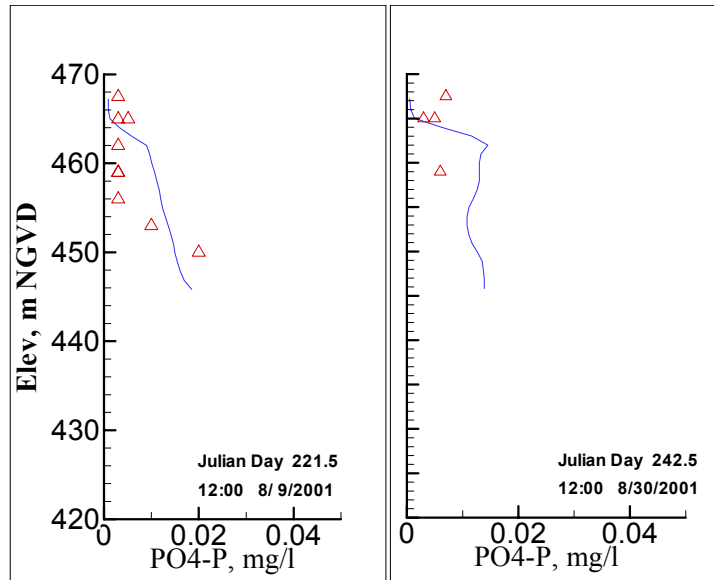


Figure 54. Run 1 soluble reactive phosphorus predictions and data for station LL3 (segment 168).

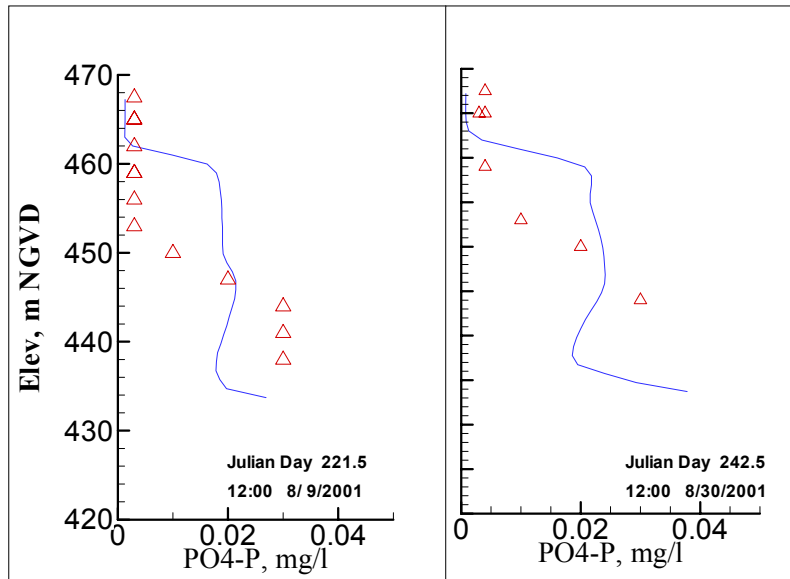
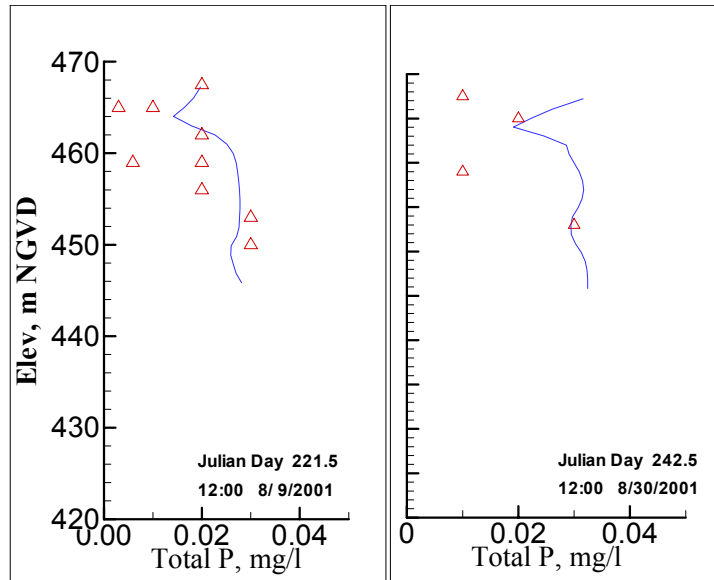
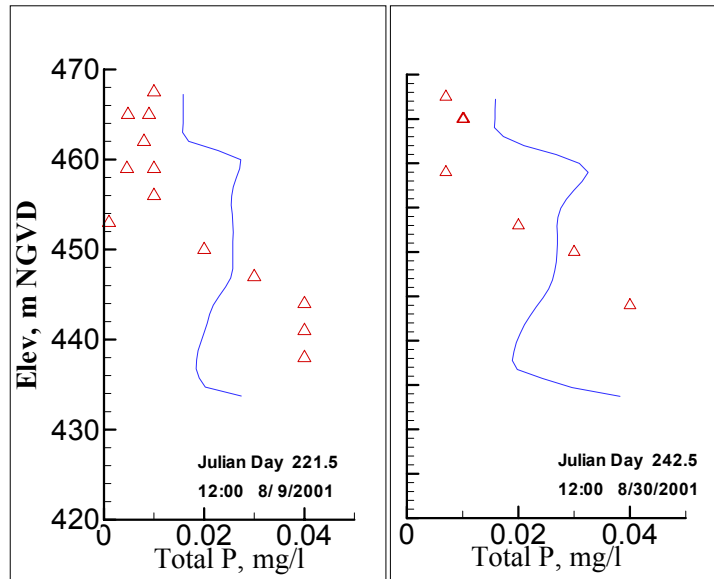


Figure 55. Run 1 soluble reactive phosphorus predictions and data for station LL1 (segment 180).



**Figure 56. Run 1 total phosphorus predictions and data for station LL3 (segment 168).**



**Figure 57. Run 1 total phosphorus predictions and data for station LL1 (segment 180).**

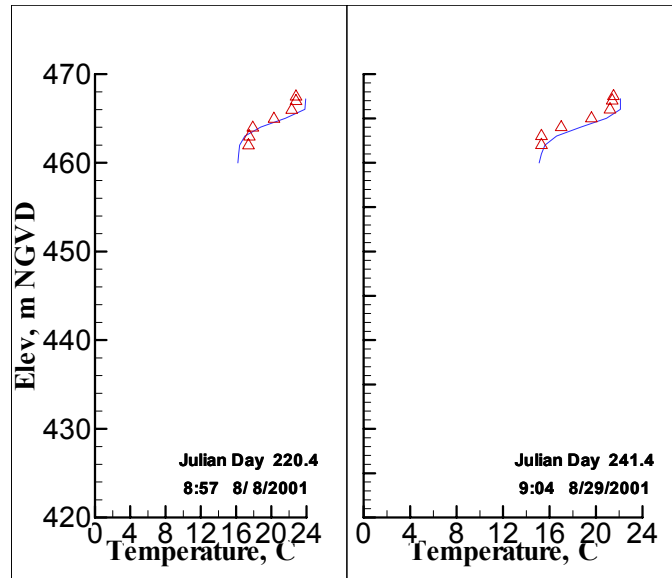


Figure 58. Run 1 temperature predictions and data for station LL5 (segment 157).

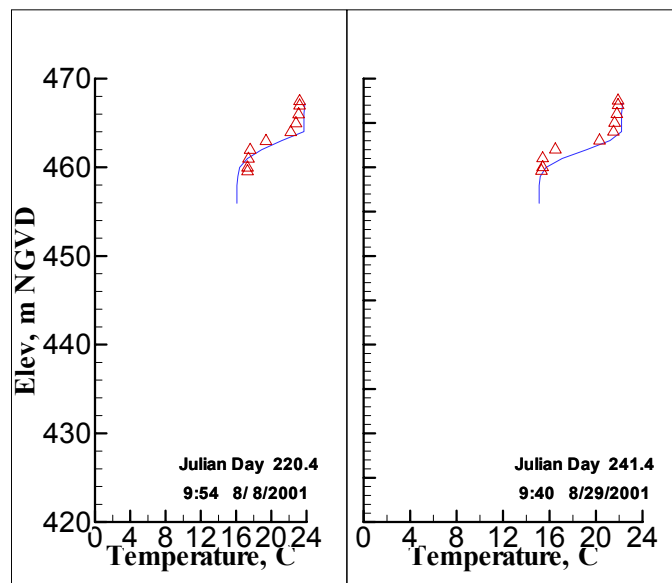


Figure 59. Run 1 temperature predictions and data for station LL4 (segment 161).

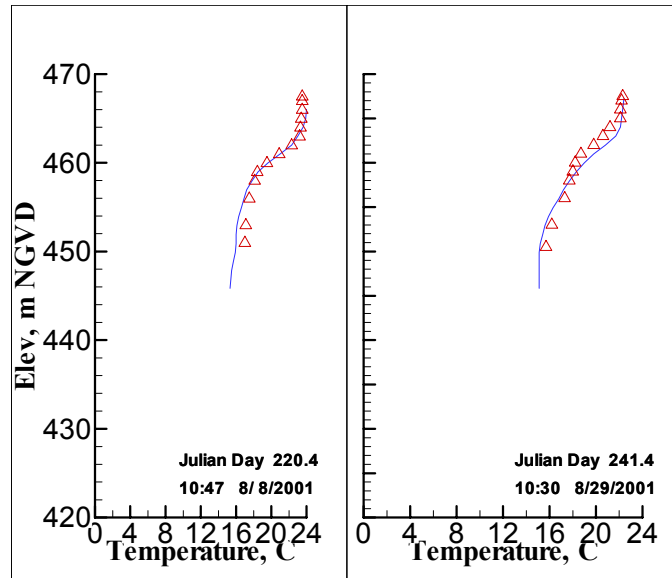


Figure 60. Run 1 temperature predictions and data for station LL3 (segment 168).

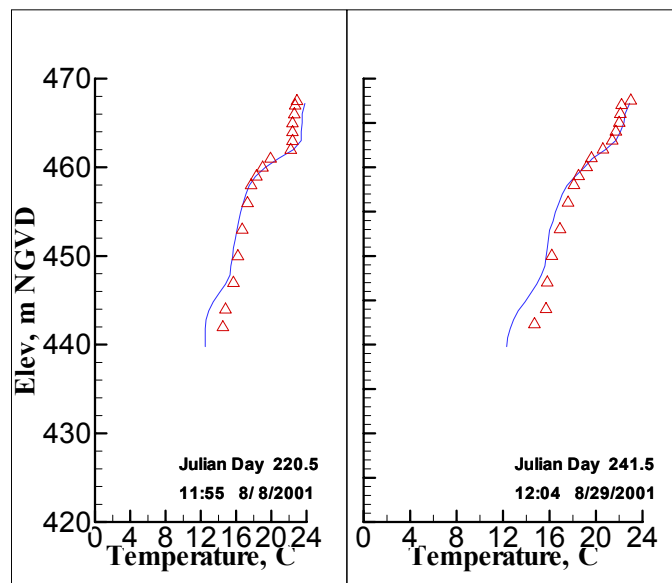


Figure 61. Run 1 temperature predictions and data for station LL2 (segment 174).

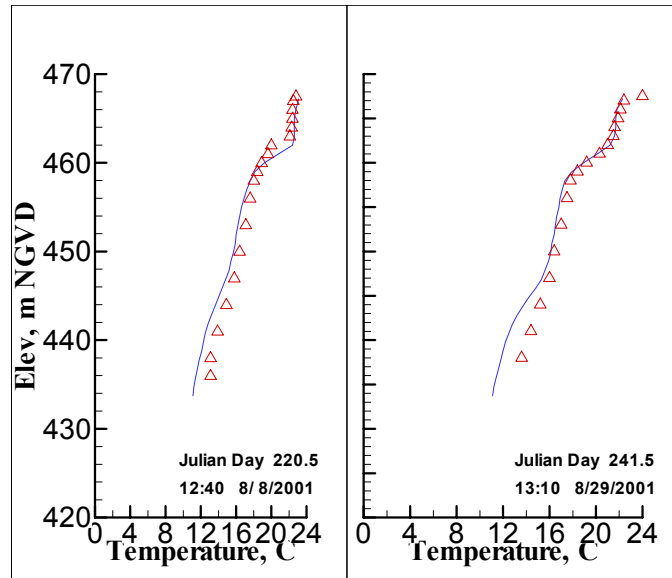


Figure 62. Run 1 temperature predictions and data for station LL1 (segment 180).

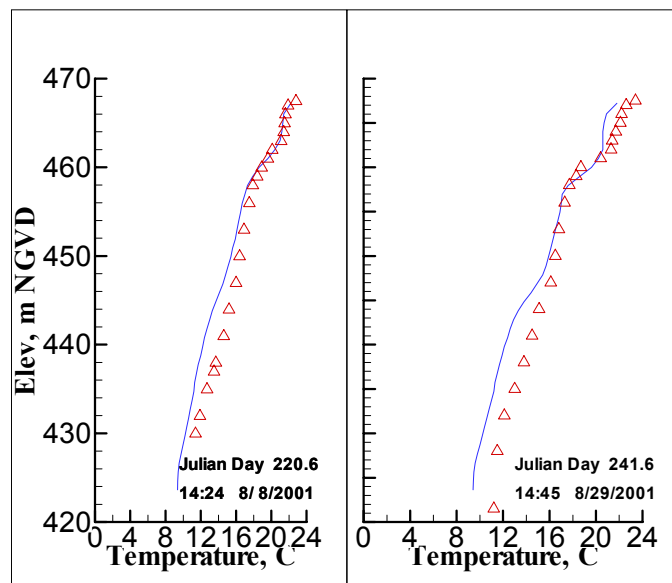


Figure 63. Run 1 temperature predictions and data for station LL0 (segment 187).



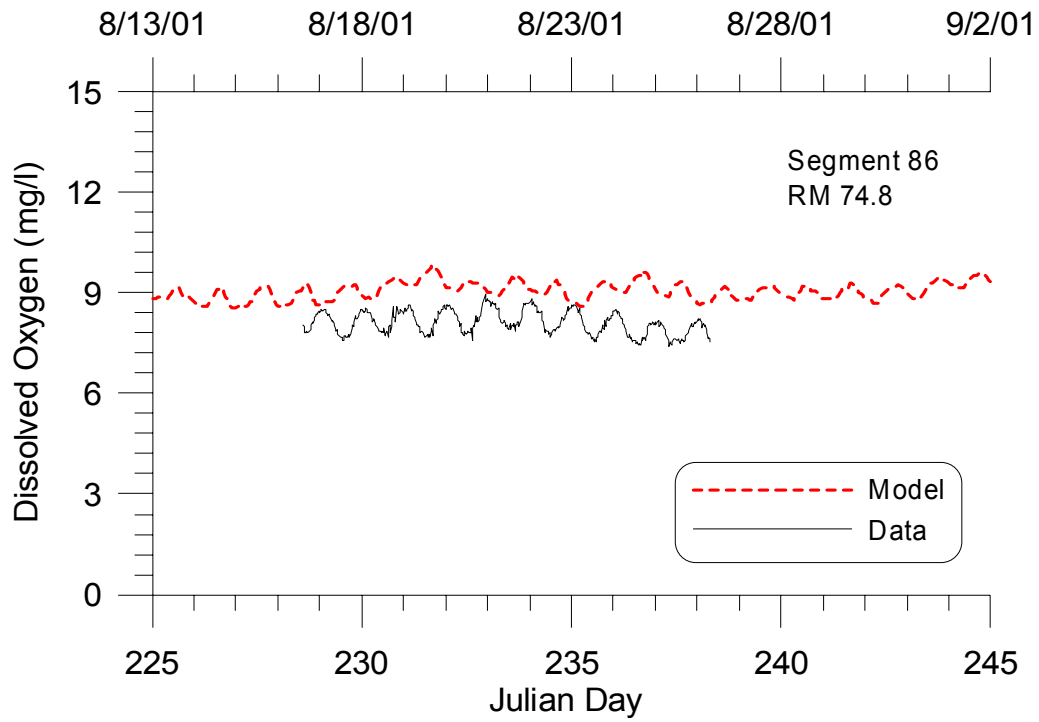


Figure 64. Comparison between run 1 dissolved oxygen predictions and continuous data for the sampling station at RM 74.8.

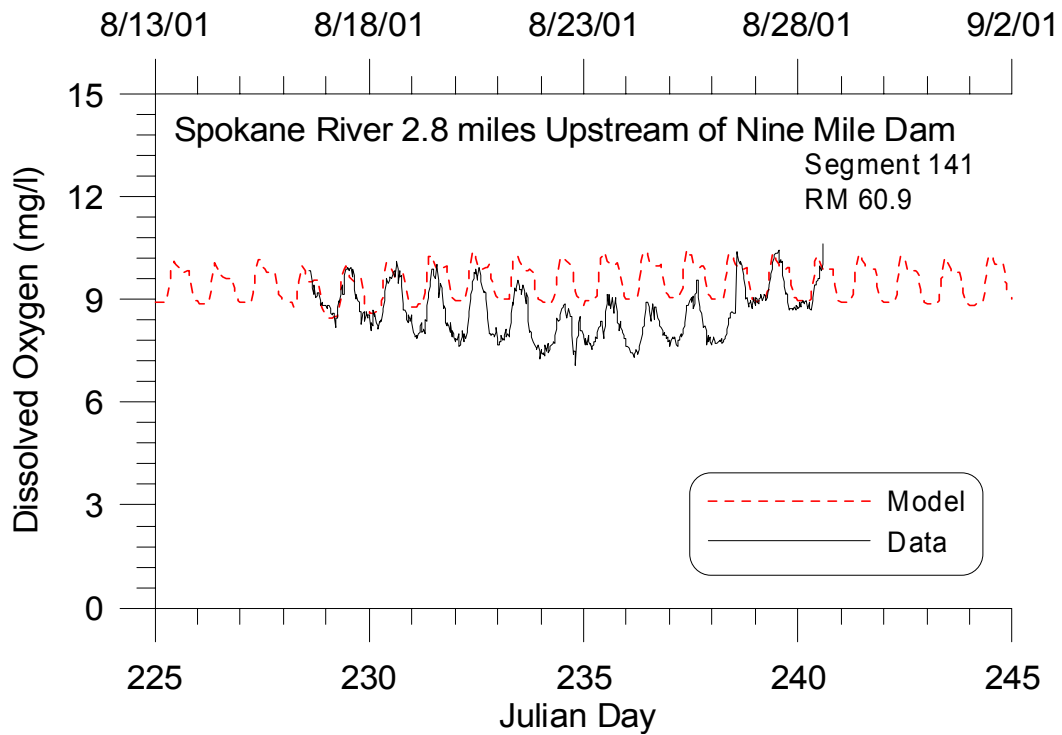


Figure 65. Comparison between run 1 dissolved oxygen predictions and continuous data for the sampling station at RM 60.9

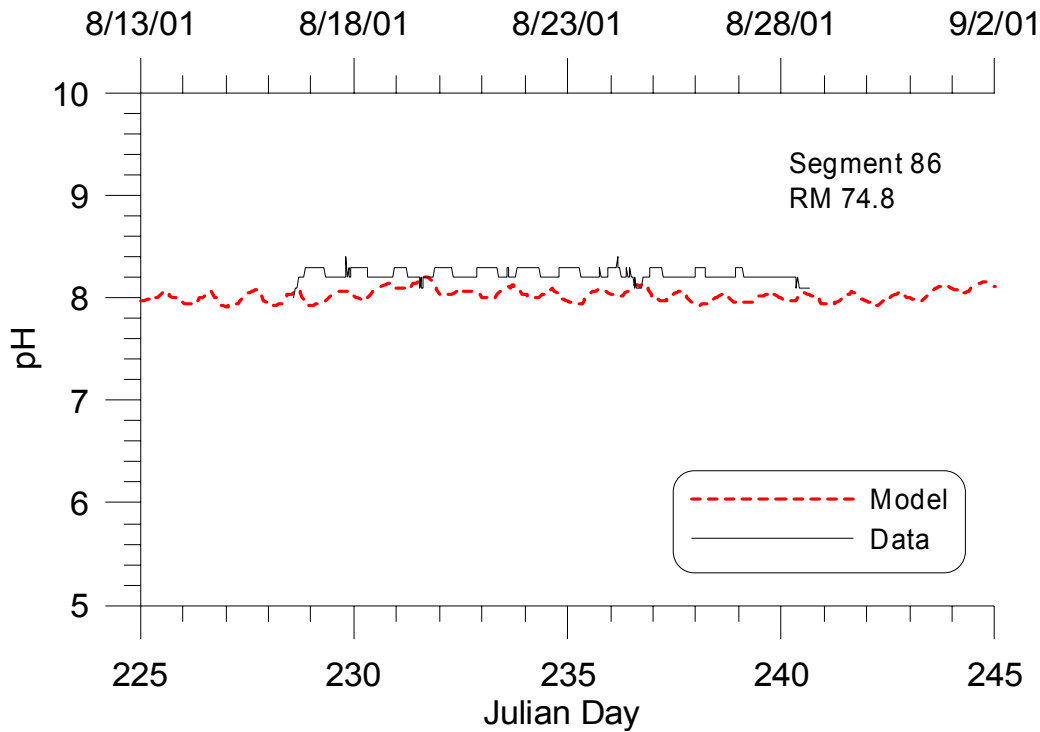


Figure 66. Comparison between run 1 pH predictions and continuous data for the sampling station at RM 74.8.

## Run 2 - Blue green settling rate of +0.01 m/d

### Long Lake

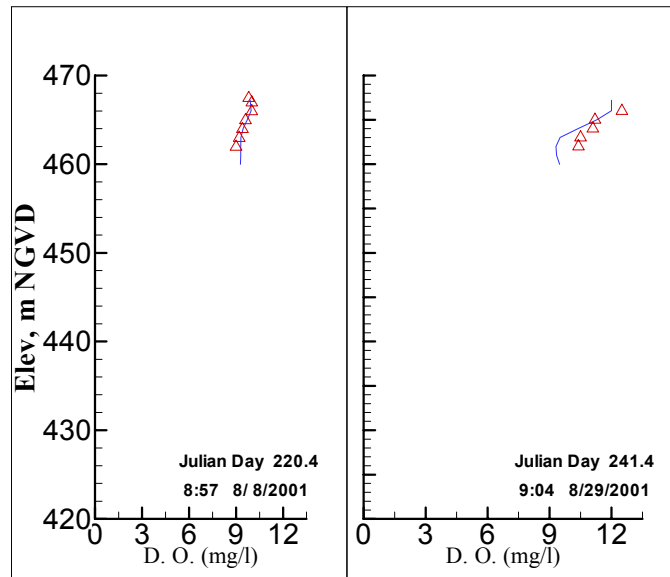
A settling rate of 0.01 m/d for blue-green algae resulted in algae biomass being more dispersed when compared to the simulation using a settling rate of  $-2$  m/d. Nevertheless, the low positive settling rate still kept algae populations near the surface where they could be advected upstream by surface currents induced by the wind. Figure 67 through Figure 72 show dissolved oxygen profile predictions and data. Error statistics for dissolved oxygen predictions are shown in Table 4. Similar to Run 1, dissolved oxygen predictions in the epilimnion are much improved. pH predictions are shown in Figure 73 through Figure 78. Chlorophyll *a* predictions in Figure 79 through Figure 81 show that concentrations were more dispersed relative to Run 1. Model predicted soluble reactive phosphorus concentration and data are plotted in Figure 82 and Figure 83. Total phosphorus concentrations are shown in Figure 84 and Figure 85.

### Spokane River

Dissolved oxygen predictions in the river are shown in Figure 86 and Figure 87. Figure 88 shows the comparison between pH predictions and data at RM 74.8. Chl *a* and soluble reactive phosphorus are plotted in Figure 89 and Figure 90, respectively.

**Table 4. Run 2 dissolved oxygen profile error statistics, 2001**

Site	n, # of data profile comparisons	DO model –data error statistics	
		AME, mg/L	RMS error, mg/L
LL0	2	0.83	1.05
LL1	2	1.15	1.34
LL2	2	1.13	1.33
LL3	2	0.75	0.90
LL4	2	0.75	0.90
LL5	2	0.49	0.58
Avg.		0.85	1.02



**Figure 67. Run 2 dissolved oxygen predictions and data for station LL5 (segment 157).**

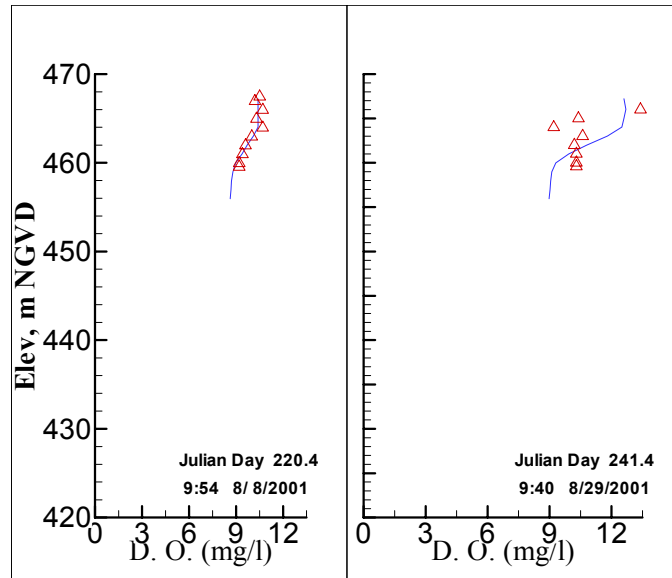


Figure 68. Run 2 dissolved oxygen predictions and data for station LL4 (segment 161).

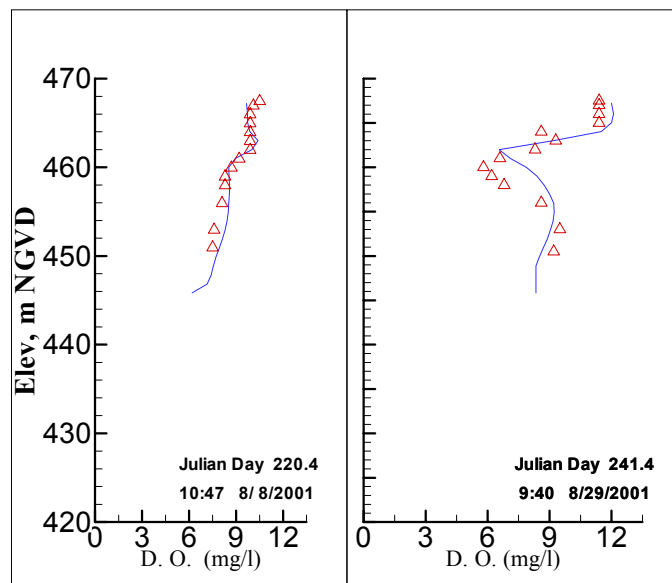


Figure 69. Run 2 dissolved oxygen predictions and data for station LL3 (segment 168).

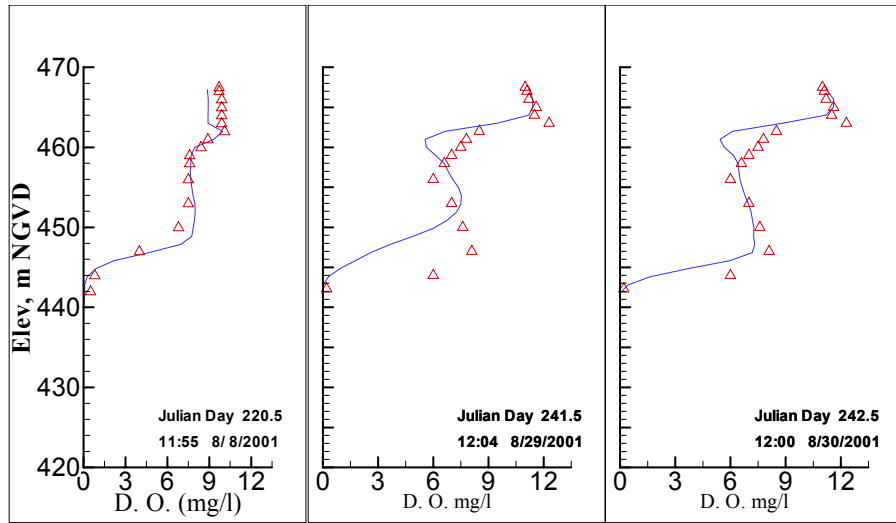


Figure 70. Run 2 dissolved oxygen predictions and data for station LL2 (segment 174).

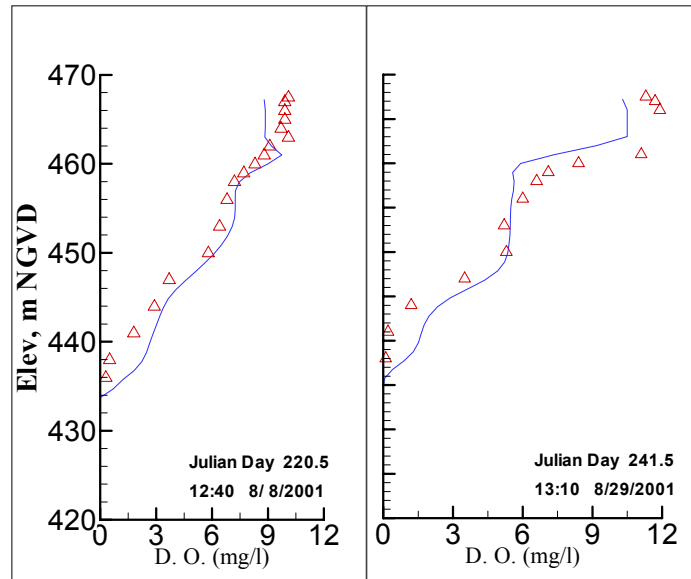


Figure 71. Run 2 dissolved oxygen predictions and data for station LL1 (segment 180).

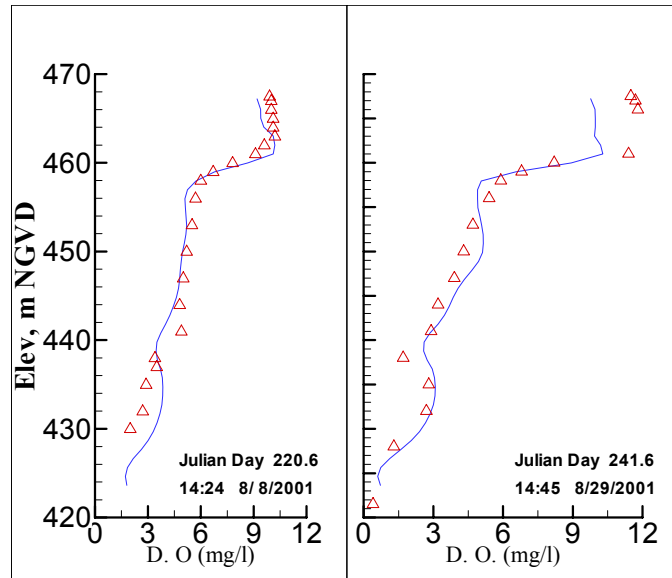


Figure 72. Run 2 dissolved oxygen predictions and data for station LL0 (segment 187).

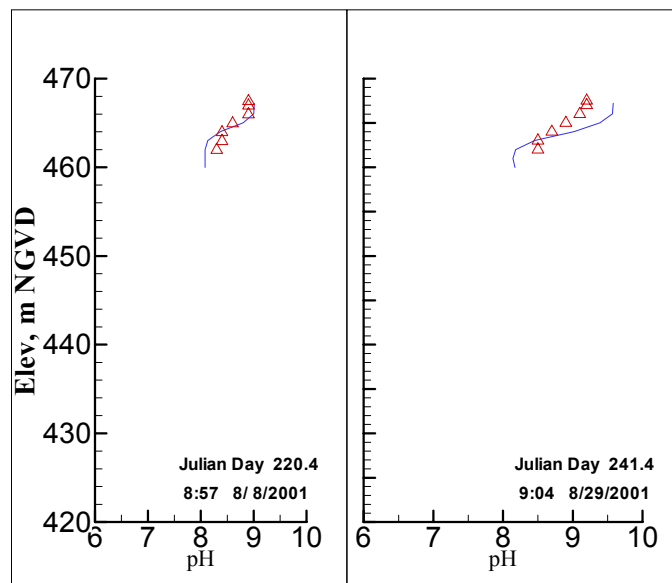


Figure 73. Run 2 pH predictions and data for station LL5 (segment 157).

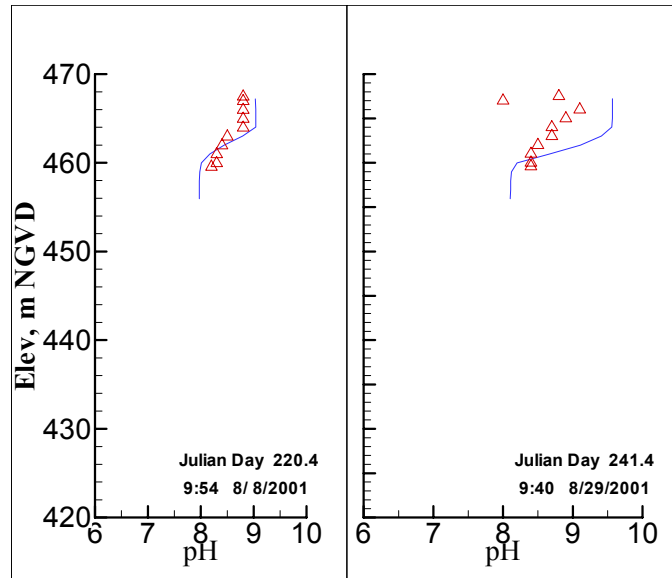


Figure 74. Run 2 pH predictions and data for station LL4 (segment 161).

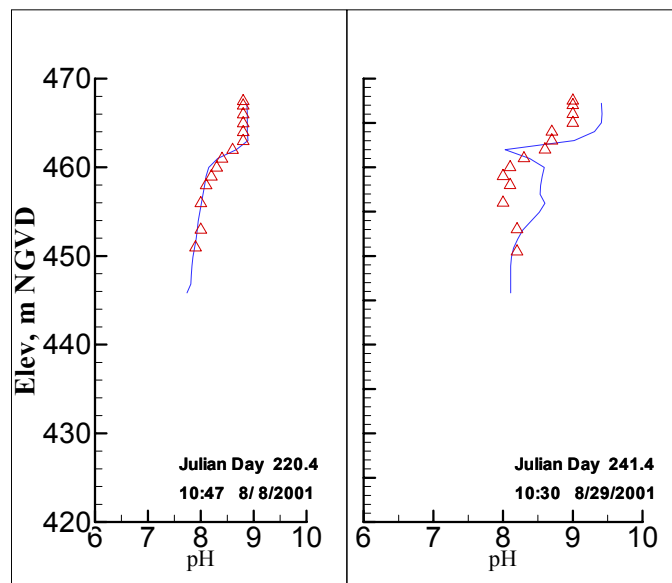


Figure 75. Run 2 pH predictions and data for station LL3 (segment 168).

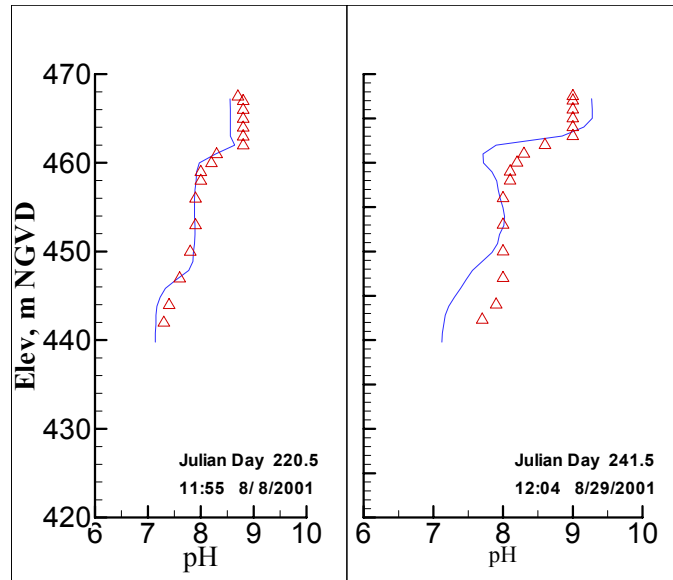


Figure 76. Run 2 pH predictions and data for station LL2 (segment 174).

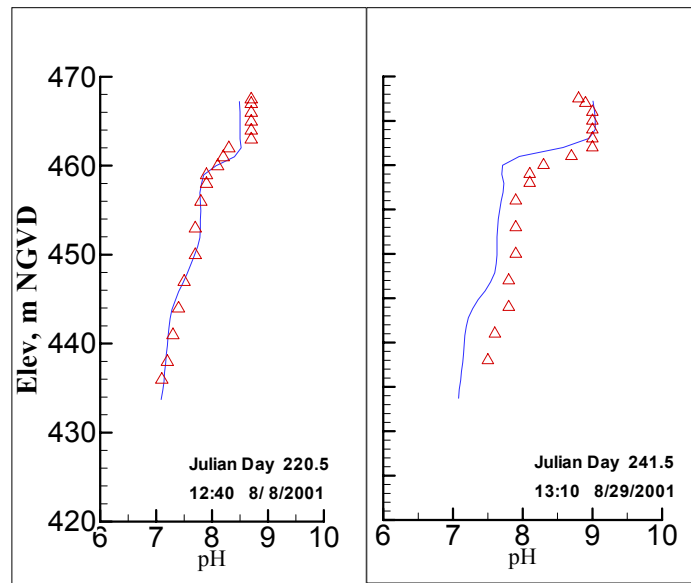


Figure 77. Run 2 pH predictions and data for station LL1 (segment 180).



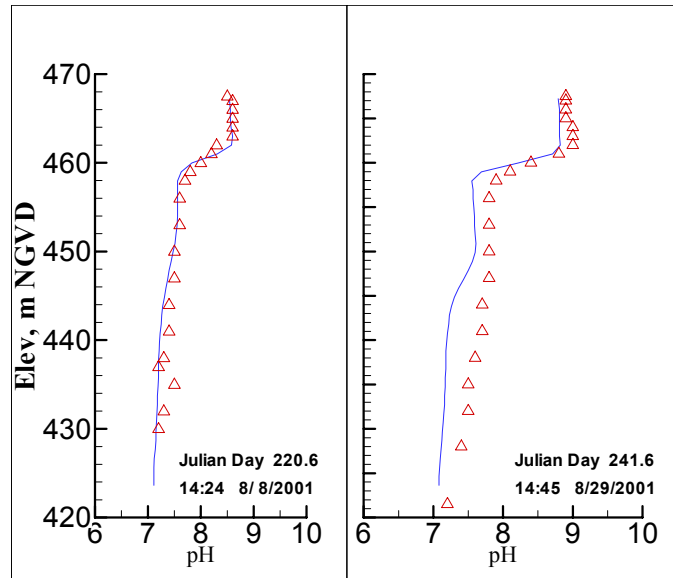


Figure 78. Run 2 pH predictions and data for station LL0 (segment 187).

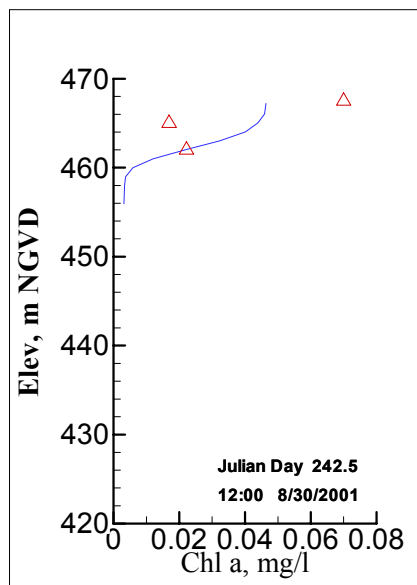


Figure 79. Run 2 chlorophyll a predictions and data for station LL4 (segment 161).

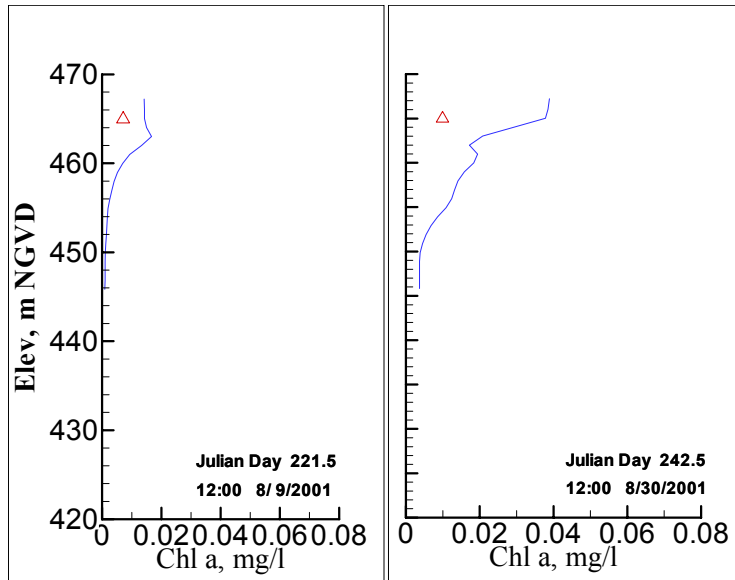


Figure 80. Run 2 chlorophyll a predictions and data for station LL3 (segment 168).

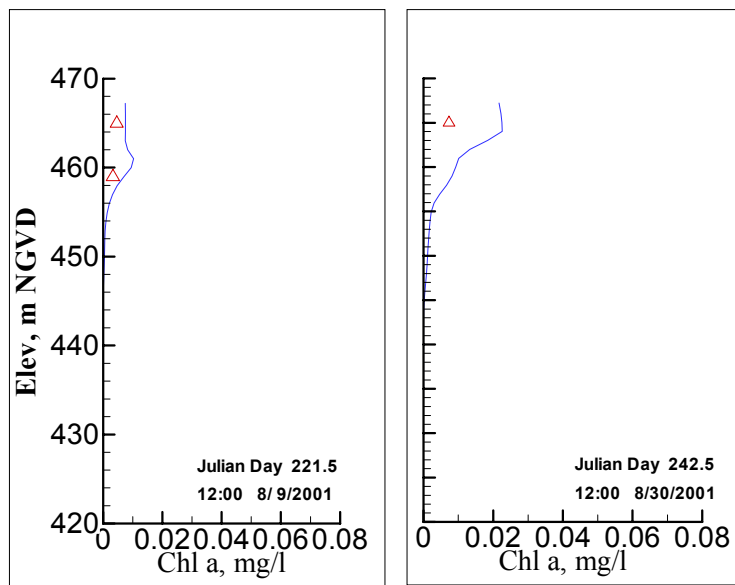


Figure 81. Run 2 chlorophyll a predictions and data for station LL1 (segment 180).

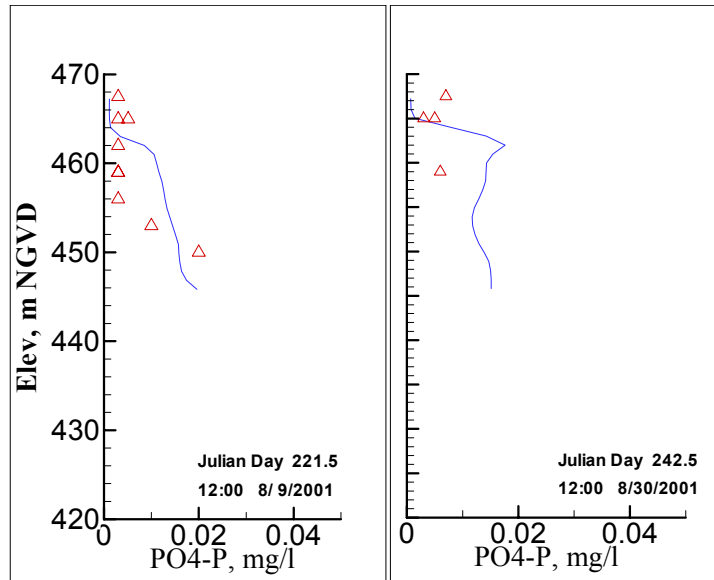


Figure 82. Run 2 soluble reactive phosphorus predictions and data for station LL3 (segment 168).

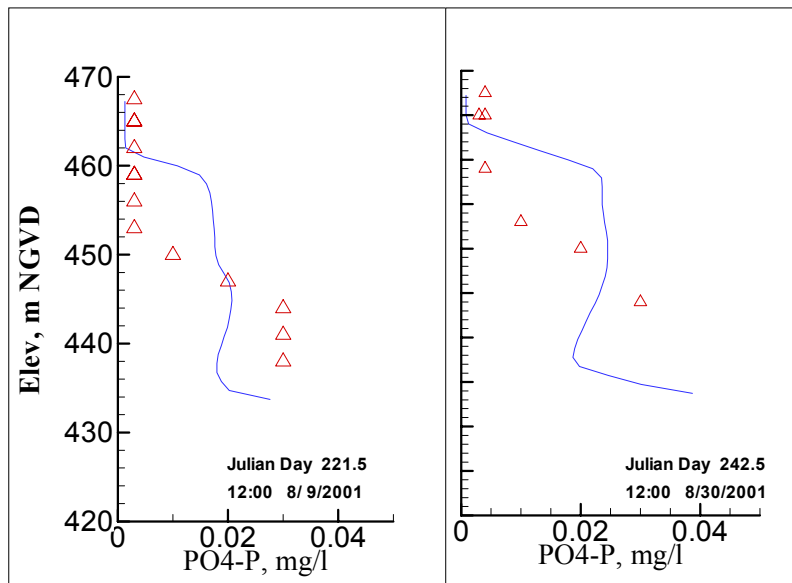


Figure 83. Run 2 soluble reactive phosphorus predictions and data for station LL1 (segment 180).

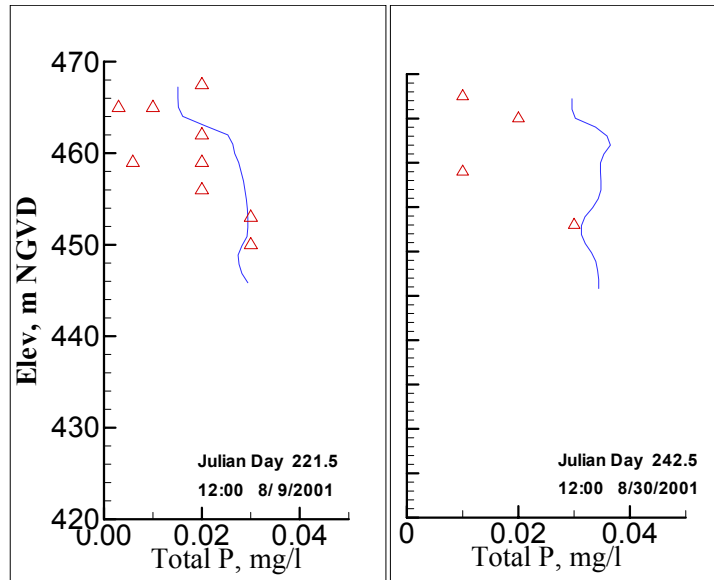


Figure 84. Run 2 total phosphorus predictions and data for station LL3 (segment 168).

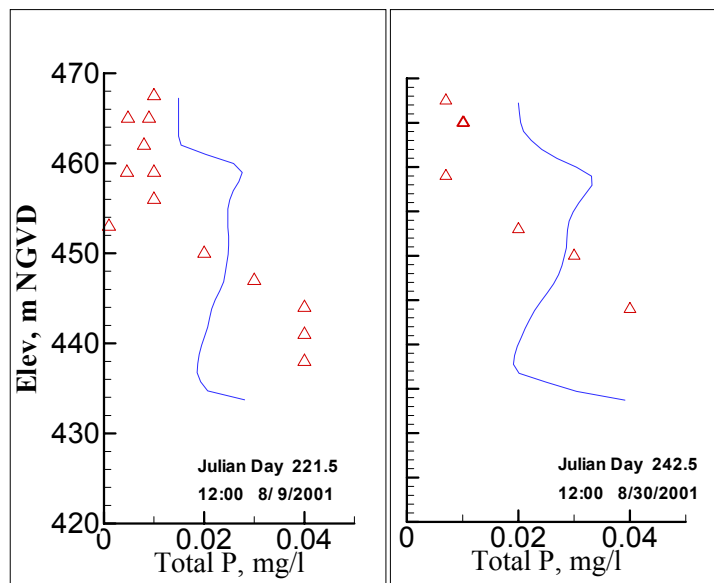


Figure 85. Run 2 total phosphorus predictions and data for station LL1 (segment 180).

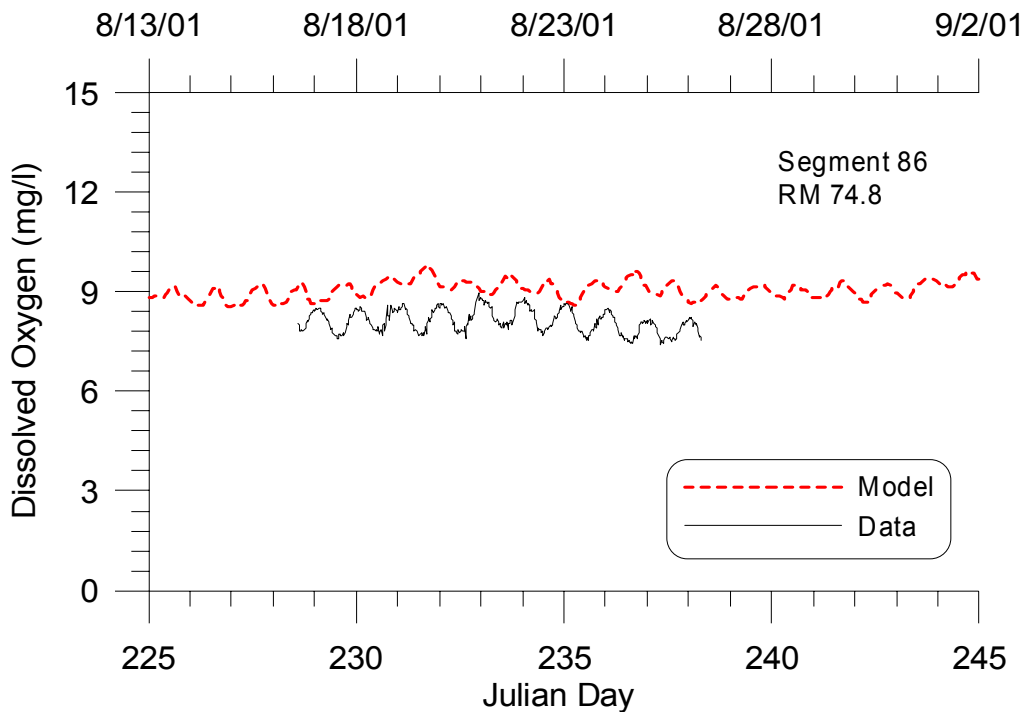


Figure 86. Comparison between run 2 dissolved oxygen predictions and continuous data for the sampling station at RM 74.8.

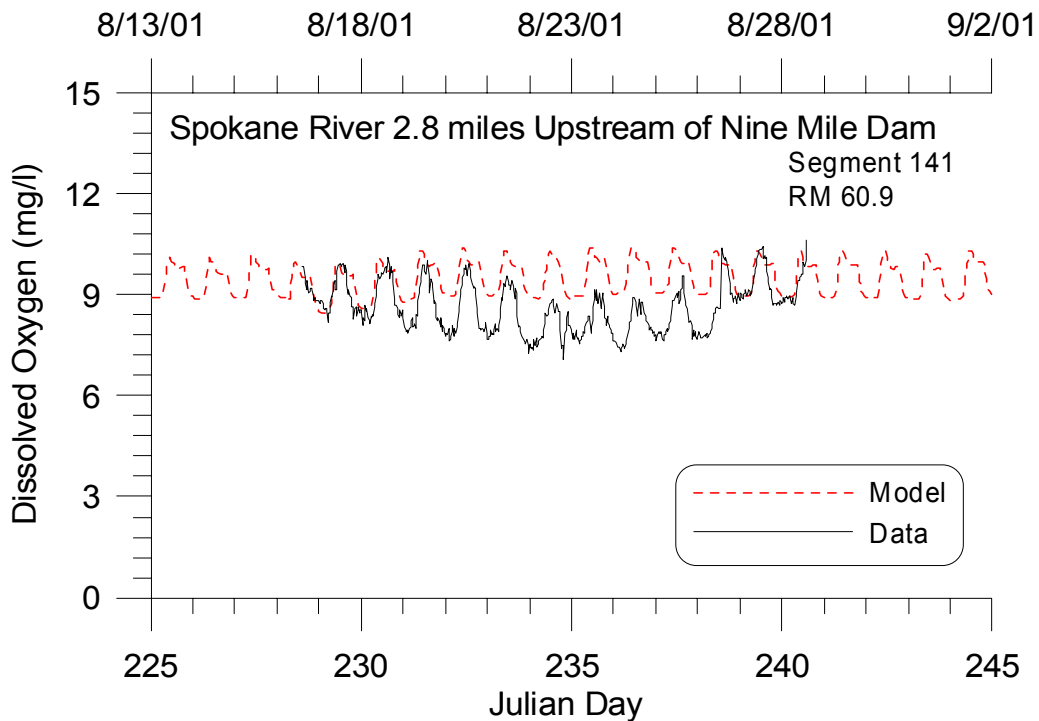


Figure 87. Comparison between run 2 dissolved oxygen predictions and continuous data for the sampling station at RM 60.9

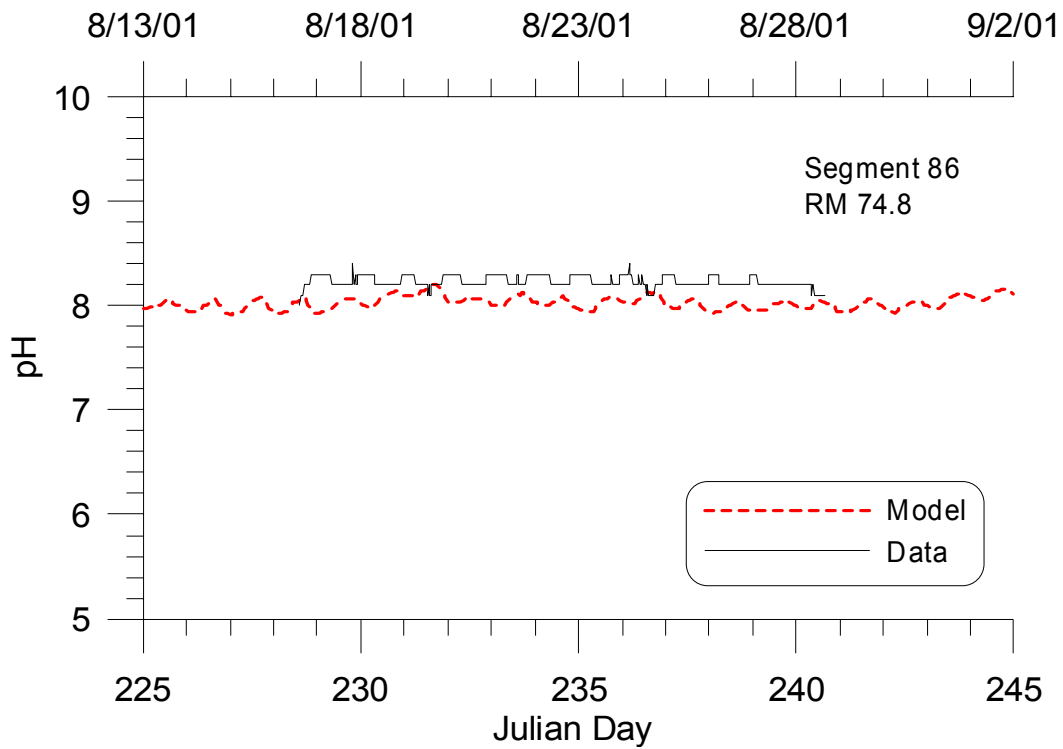


Figure 88. Comparison between run 2 pH predictions and continuous data for the sampling station at RM 74.8.

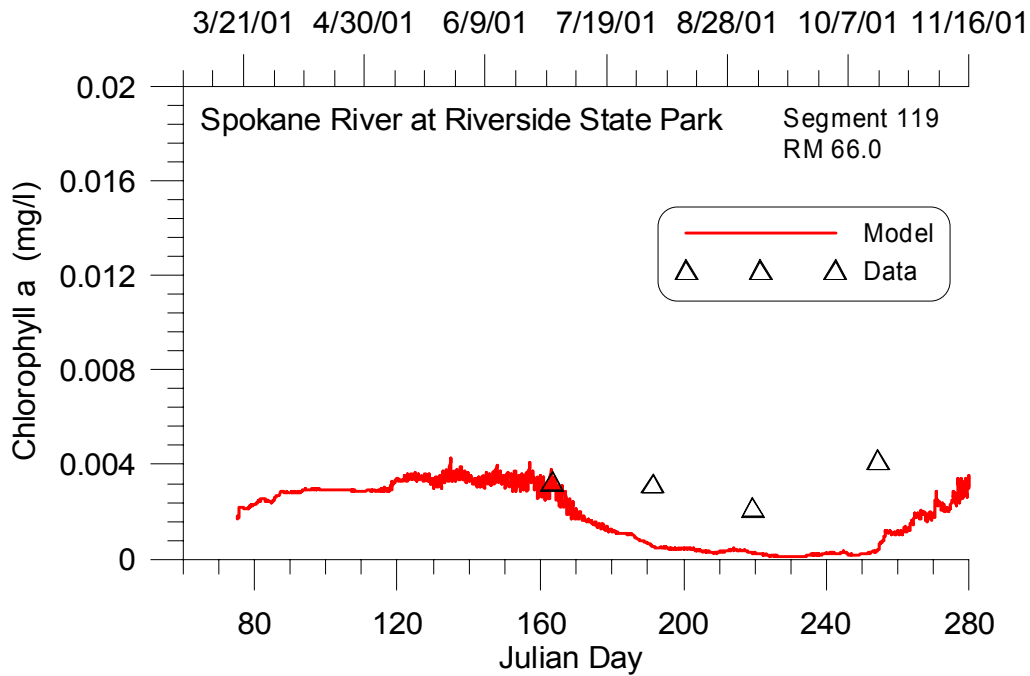


Figure 89. Comparison between run 2 chlorophyll a predictions and data for the sampling station at RM 74.8.

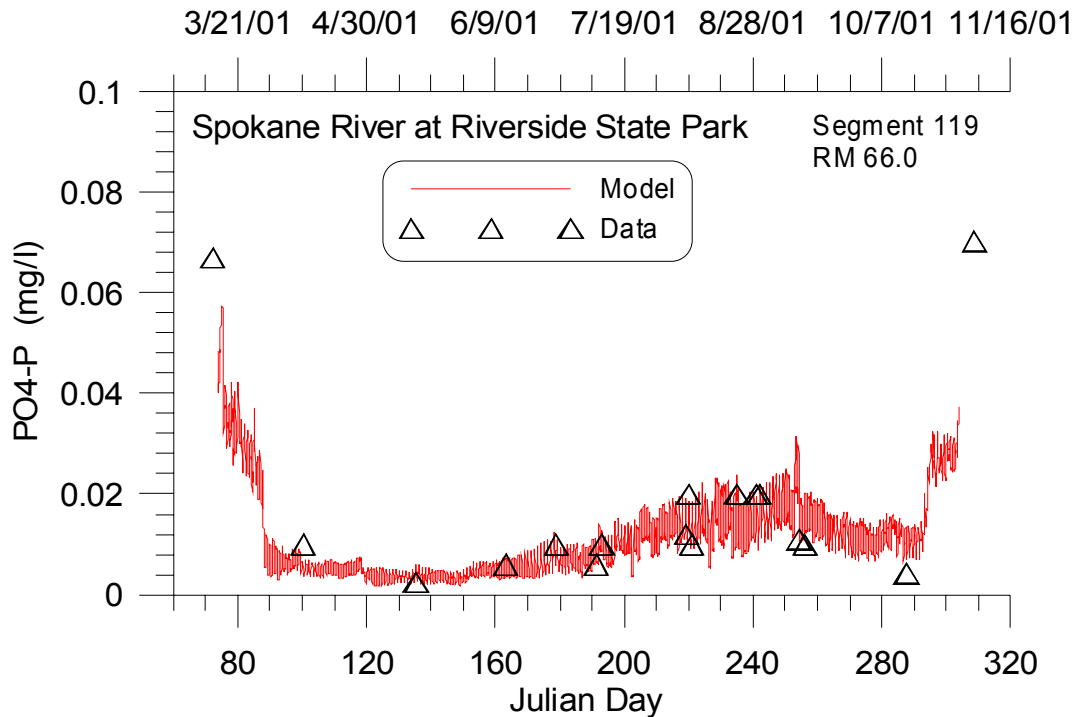


Figure 90. Comparison between run 2 soluble reactive phosphorus predictions and data for the sampling station at RM 74.8.

### Original Calibration Results

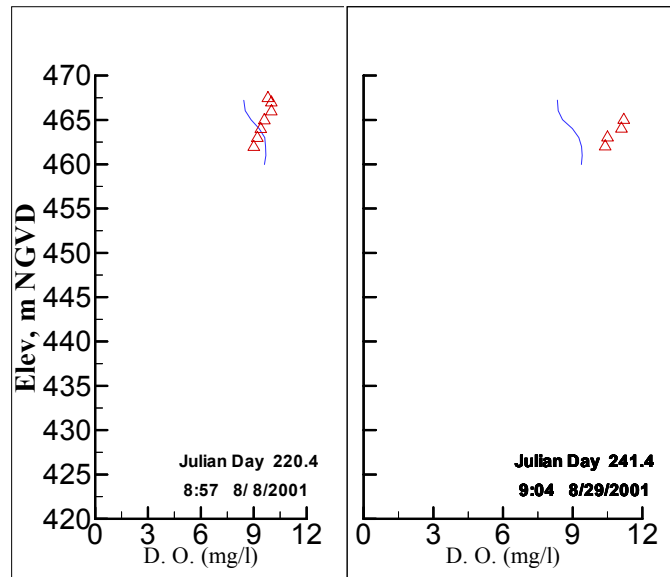
As a comparison to earlier model simulations, some of the original calibrations results (Berger et al., 2003) are shown below. Dissolved oxygen predictions for Long Lake are compared with data in Figure 91 through Figure 96. Long Lake pH predictions are shown in Figure 97 through Figure 102. Figure 103 through Figure 105 show chl *a* predictions versus observed data. Model-data comparisons of Long Lake temperature profiles are shown in Figure 106 through Figure 111.

Continuous dissolved oxygen data are compared with data in Figure 112 through Figure 116. pH predictions and continuous data are plotted in Figure 117.

The original soluble reactive phosphorus calibration at Riverside State Park is shown in Figure 122, the alkalinity calibration for Riverside State Park in Figure 123, the dissolved oxygen calibration in Figure 124, and the chl *a* calibration in Figure 125. Figure 126 shows the original ultimate CBOD calibration for Riverside State Park. The model predicted conductivity and continuous data were compared in Figure 127 through Figure 129. Dissolved oxygen statistics for Long Lake are shown in Table 5.

**Table 5. Dissolved oxygen profile error statistics, 2001**

Site	n, # of data profile comparisons	DO model –data error statistics	
		AME, mg/L	RMS error, mg/L
LL0	2	1.60	1.99
LL1	2	1.70	1.96
LL2	2	1.44	1.65
LL3	2	1.68	1.94
LL4	2	1.79	2.25
LL5	2	1.79	2.07
Avg.		1.52	1.79



**Figure 91. Comparison of model predicted vertical dissolved oxygen profiles and data for Long Lake at Station 5 (Segment 157).**



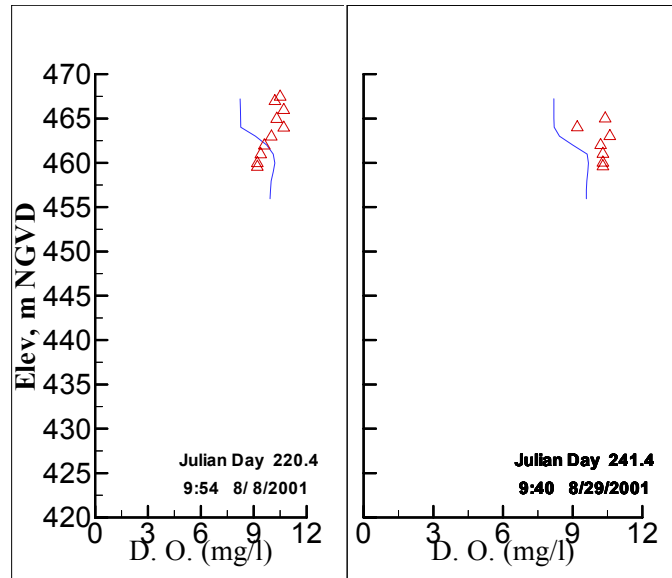


Figure 92. Comparison of model predicted vertical dissolved oxygen profiles and data for Long Lake at Station 4 (Segment 161).

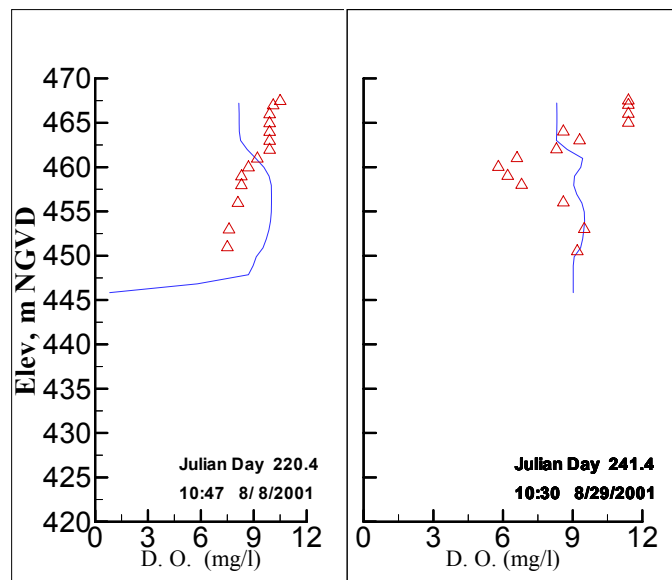
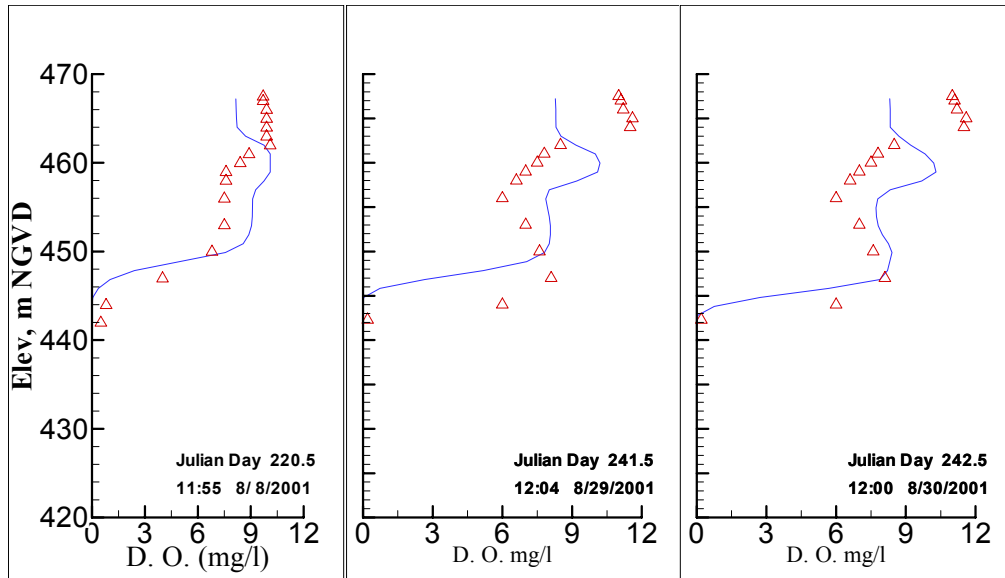
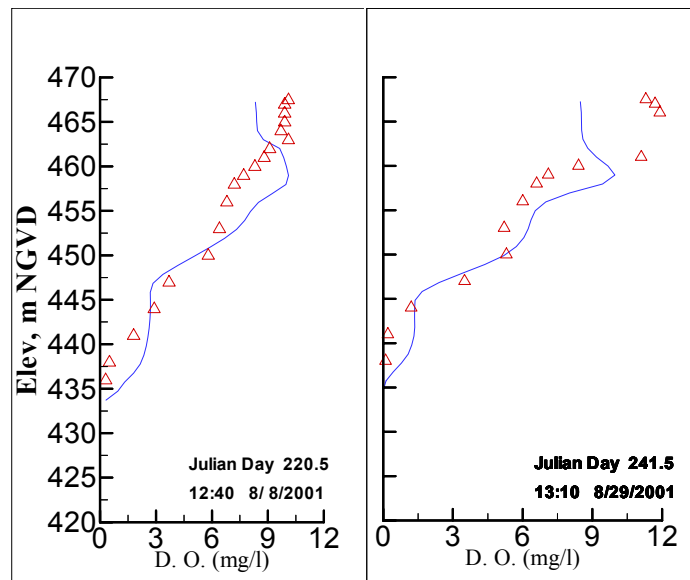


Figure 93. Comparison of model predicted vertical dissolved oxygen profiles and data for Long Lake at Station 3 (Segment 168).



**Figure 94. Comparison of model predicted vertical dissolved oxygen profiles and data for Long Lake at Station 2 (Segment 174). The frame on the right compares model predictions for Julian Day 242 with data collected on Julian Day 241.**



**Figure 95. Comparison of model predicted vertical dissolved oxygen profiles and data for Long Lake at Station 1 (Segment 180).**

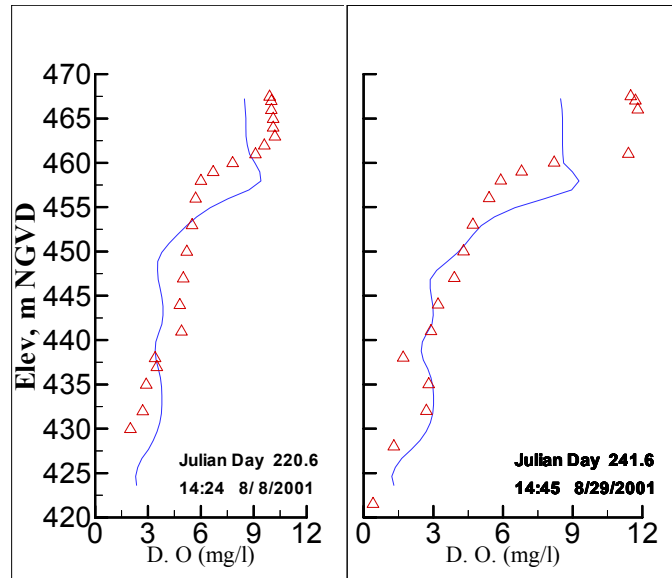


Figure 96. Comparison of model predicted vertical dissolved oxygen profiles and data for Long Lake at Station 0 (Segment 187).

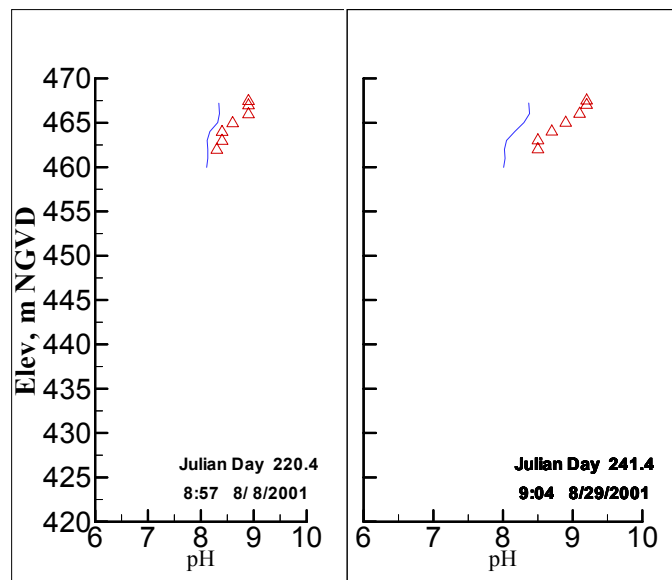
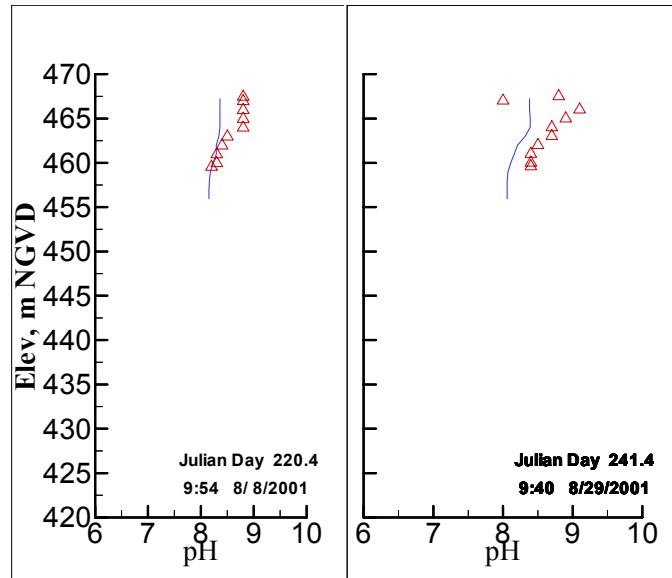
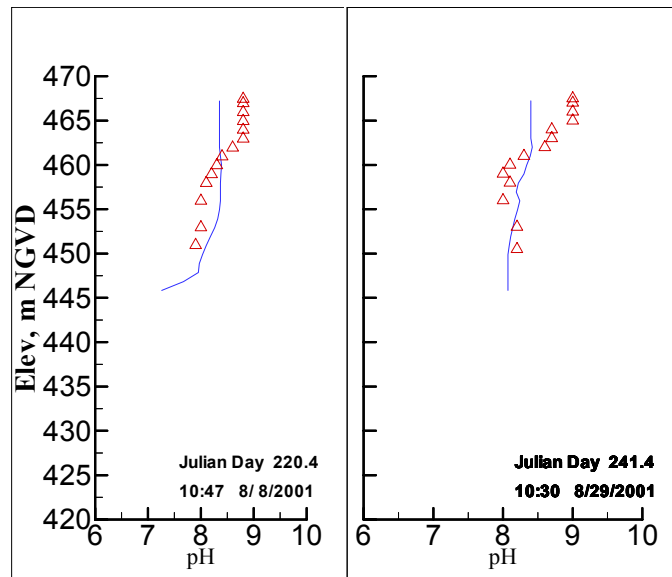


Figure 97. Comparison of model predicted vertical pH profiles and data for Long Lake at Station 5 (Segment 157).



**Figure 98. Comparison of model predicted vertical pH profiles and data for Long Lake at Station 4 (Segment 161).**



**Figure 99. Comparison of model predicted vertical pH profiles and data for Long Lake at Station 3 (Segment 168).**

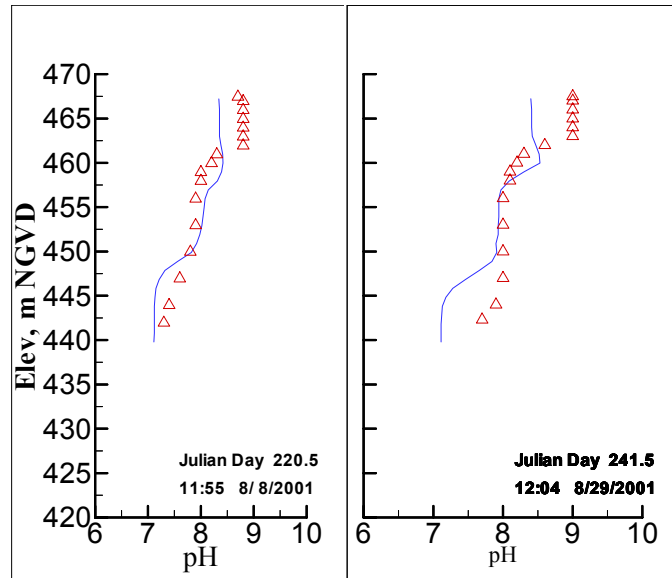


Figure 100. Comparison of model predicted vertical pH profiles and data for Long Lake at Station 2 (Segment 174).

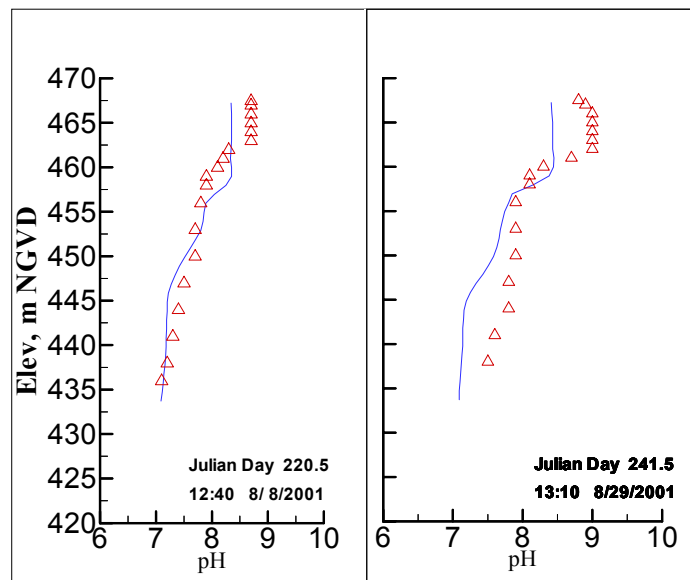


Figure 101. Comparison of model predicted vertical pH profiles and data for Long Lake at Station 1 (Segment 180).

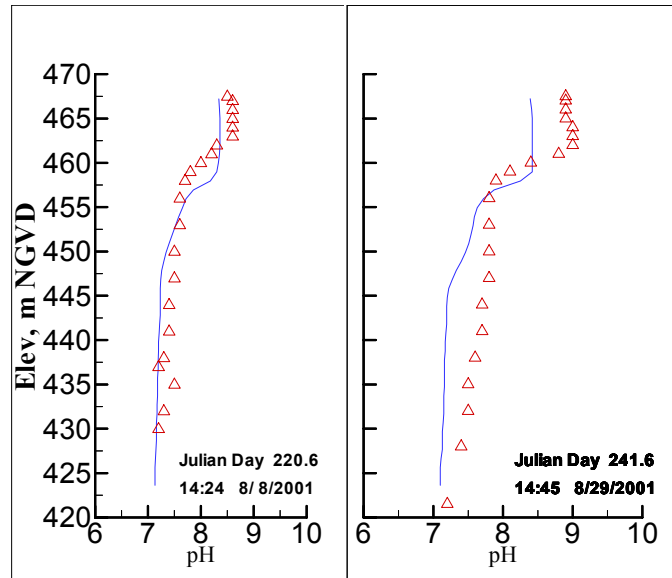


Figure 102. Comparison of model predicted vertical pH profiles and data for Long Lake at Station 0 (Segment 187).

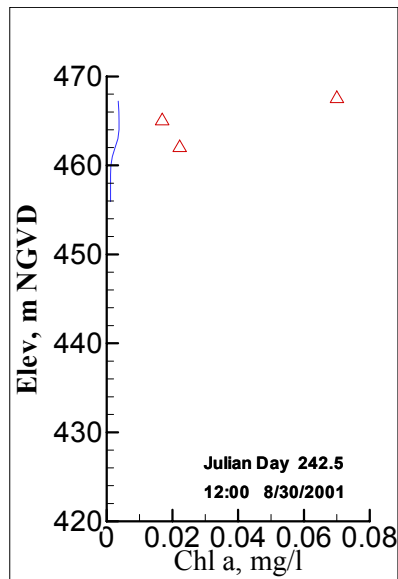


Figure 103. Comparison of model predicted vertical chlorophyll a profiles and data for Long Lake at Station 4 (Segment 161).

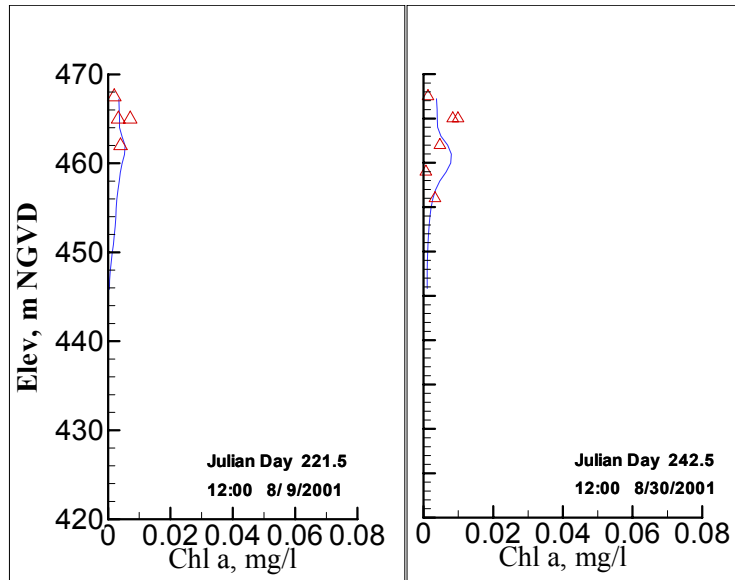


Figure 104. Comparison of model predicted vertical chlorophyll a profiles and data for Long Lake at Station 3 (Segment 168).

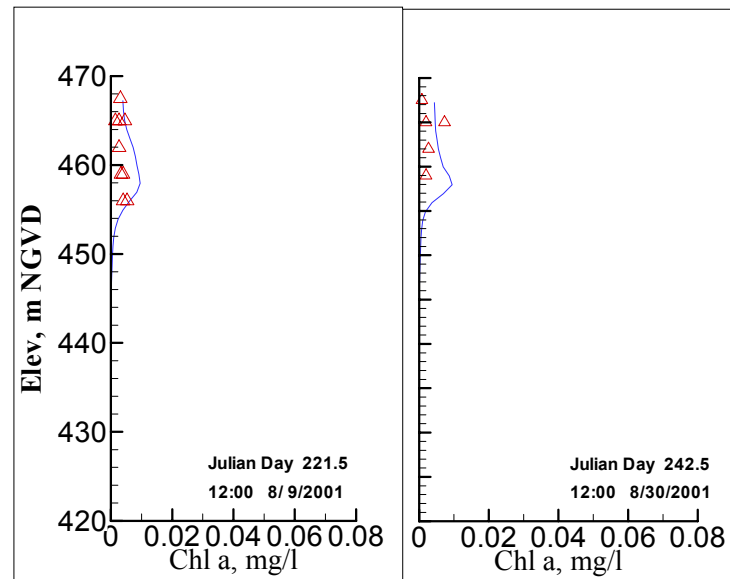
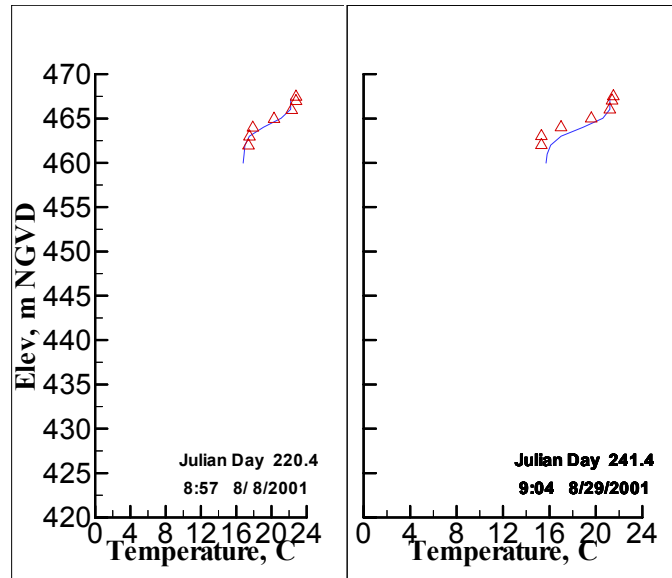
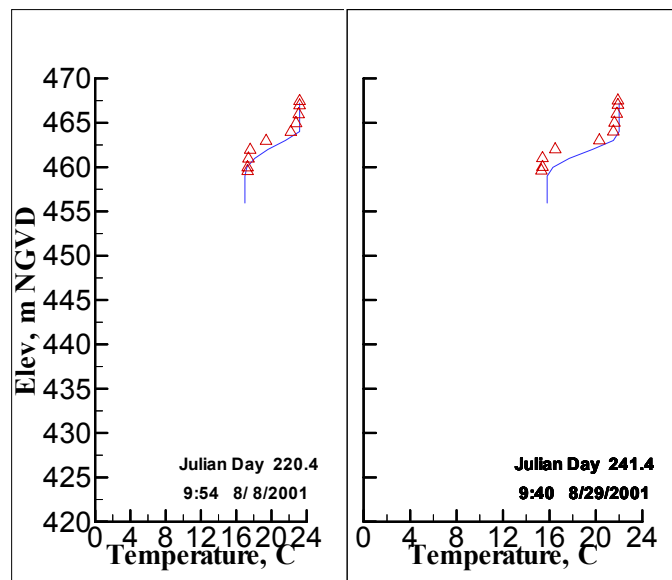


Figure 105. Comparison of model predicted vertical chlorophyll a profiles and data for Long Lake at Station 1 (Segment 180).



**Figure 106. Comparison of model predicted vertical temperature profiles and data for Long Lake at Station 5 (Segment 157).**



**Figure 107. Comparison of model predicted vertical temperature profiles and data for Long Lake at Station 4 (Segment 161).**



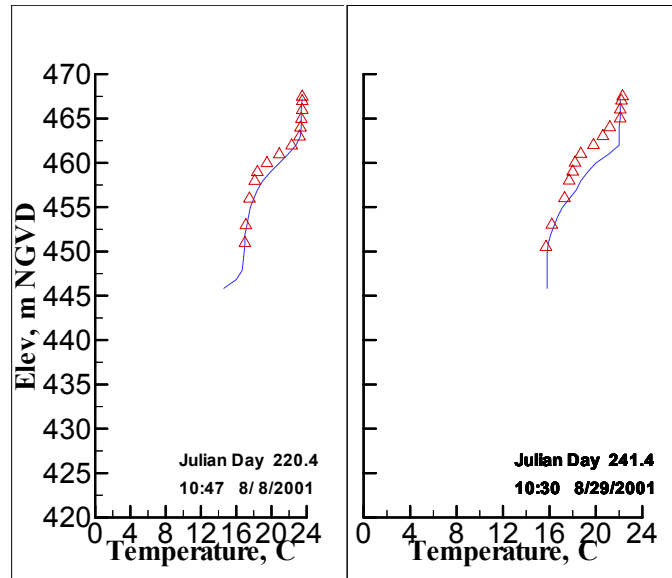


Figure 108. Comparison of model predicted vertical temperature profiles and data for Long Lake at Station 3 (Segment 168).

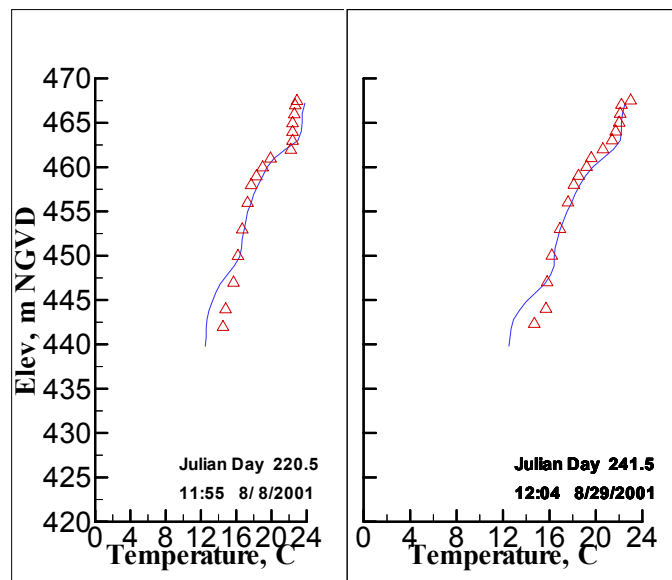


Figure 109. Comparison of model predicted vertical temperature profiles and data for Long Lake at Station 2 (Segment 174).

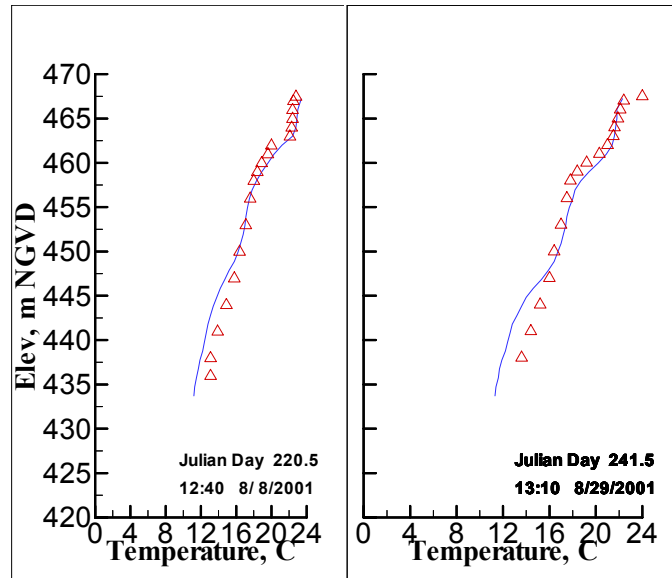


Figure 110. Comparison of model predicted vertical temperature profiles and data for Long Lake at Station 1 (Segment 180).

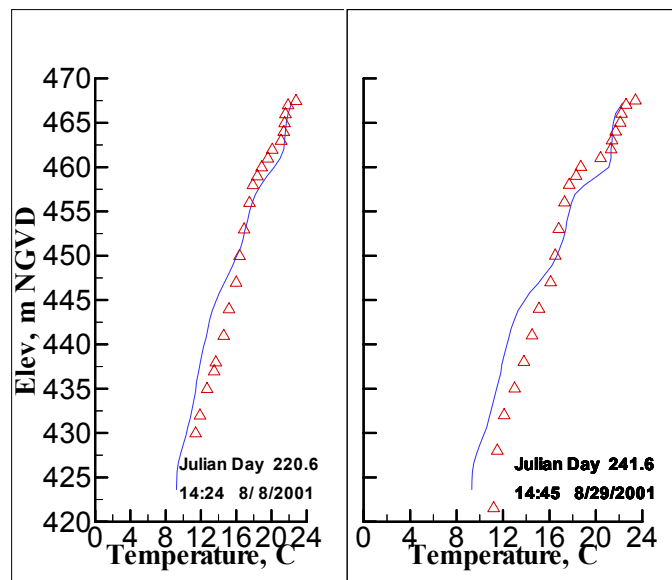


Figure 111. Comparison of model predicted vertical temperature profiles and data for Long Lake at Station 0 (Segment 187).

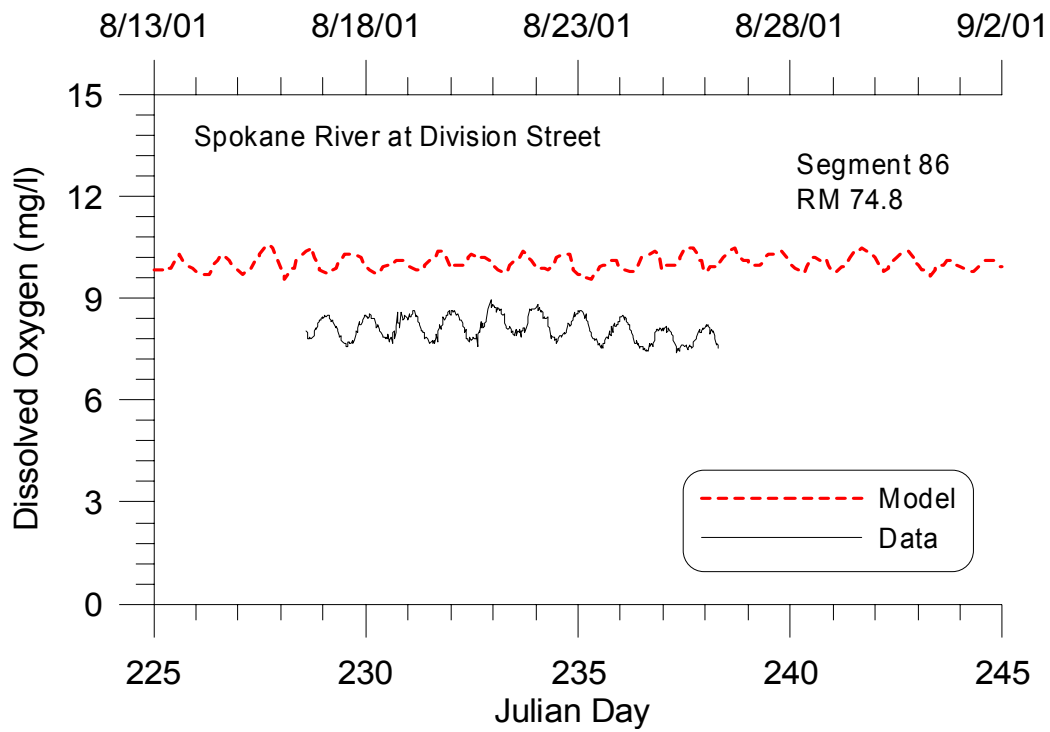


Figure 112. Dissolved oxygen predictions for Division Street (RM74.8) compared with continuous data.

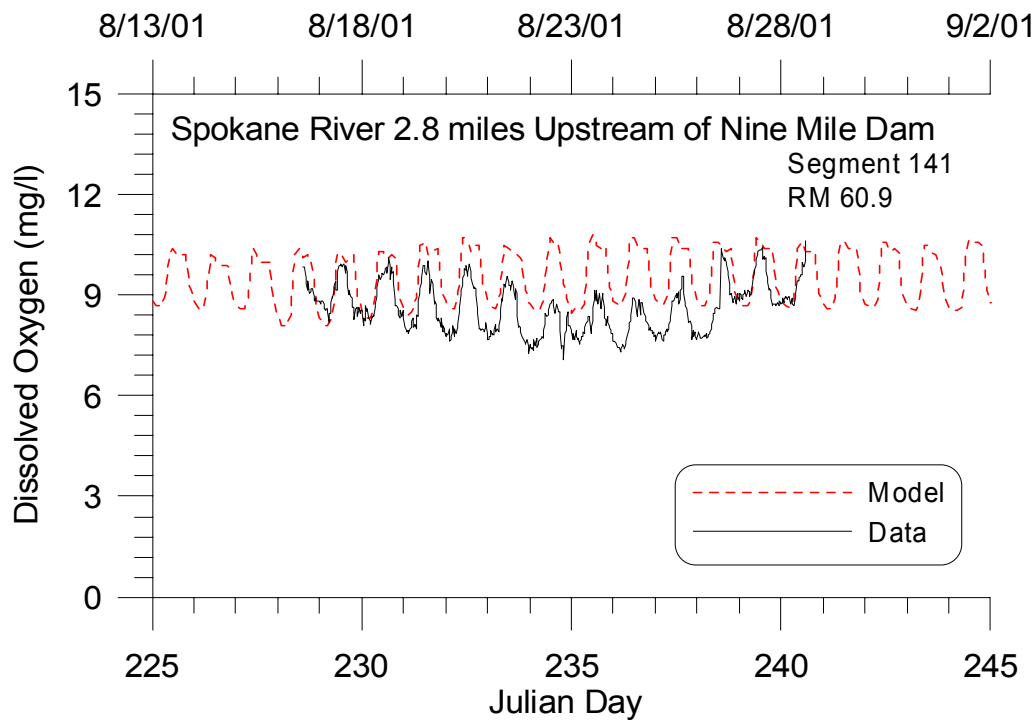


Figure 113. Dissolved oxygen predictions for RM 60.9 compared with continuous data.

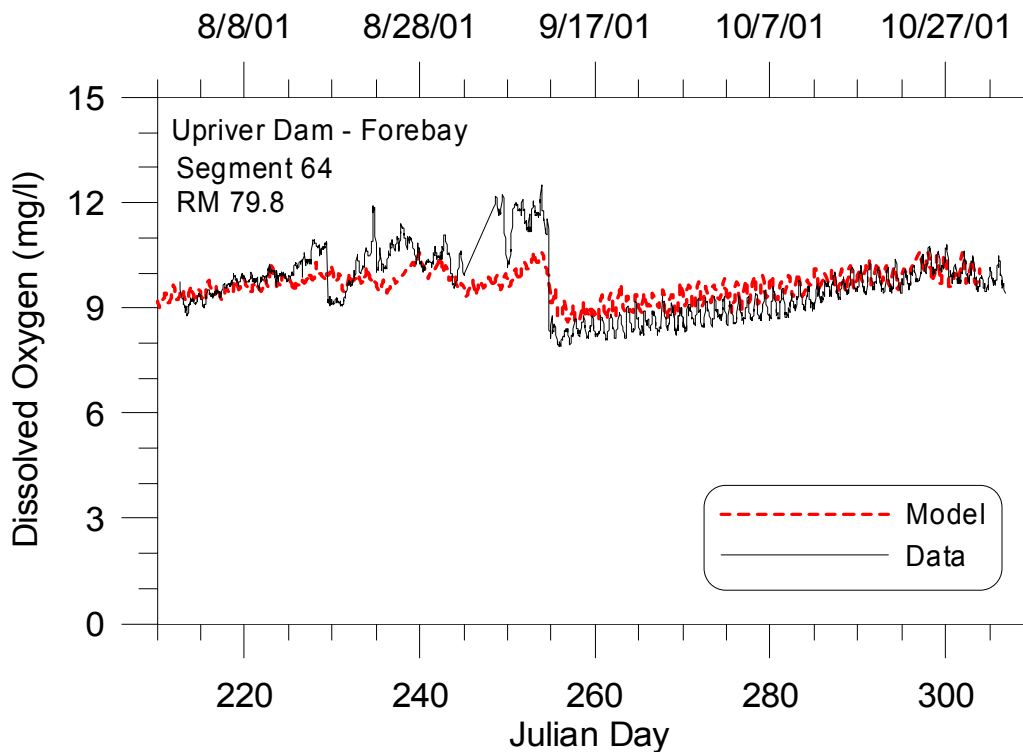


Figure 114. Dissolved oxygen predictions for the Upriver Dam Forebay (RM 79.8) compared with continuous data.

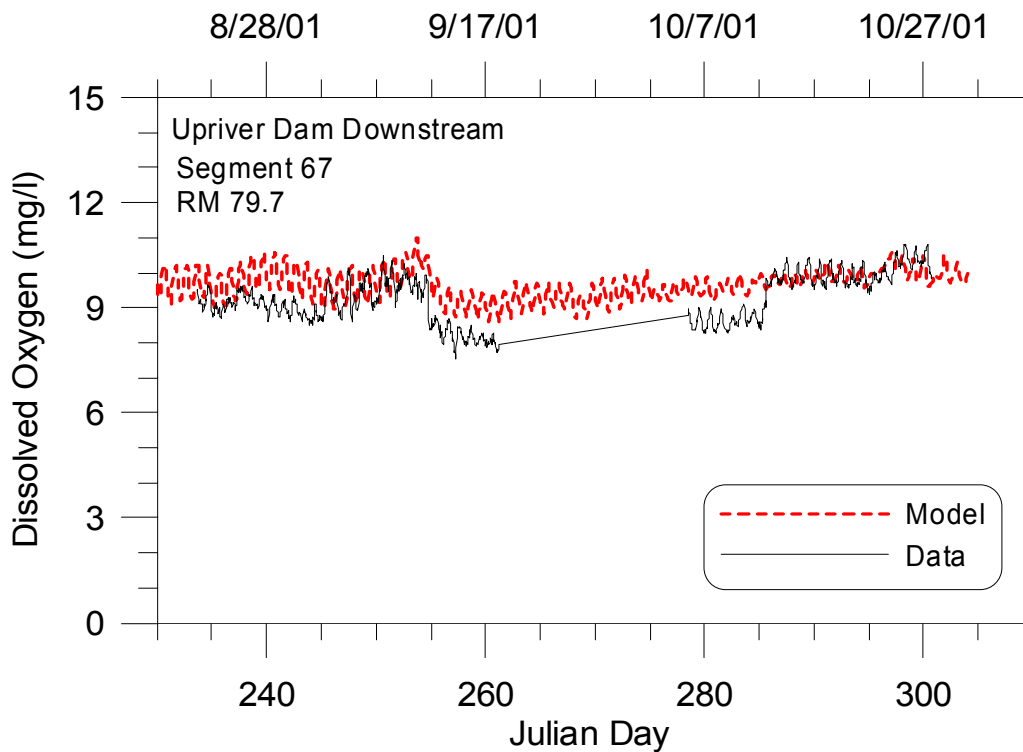


Figure 115. Dissolved oxygen predictions for downstream of Upriver Dam (RM 79.7) compared with continuous data.

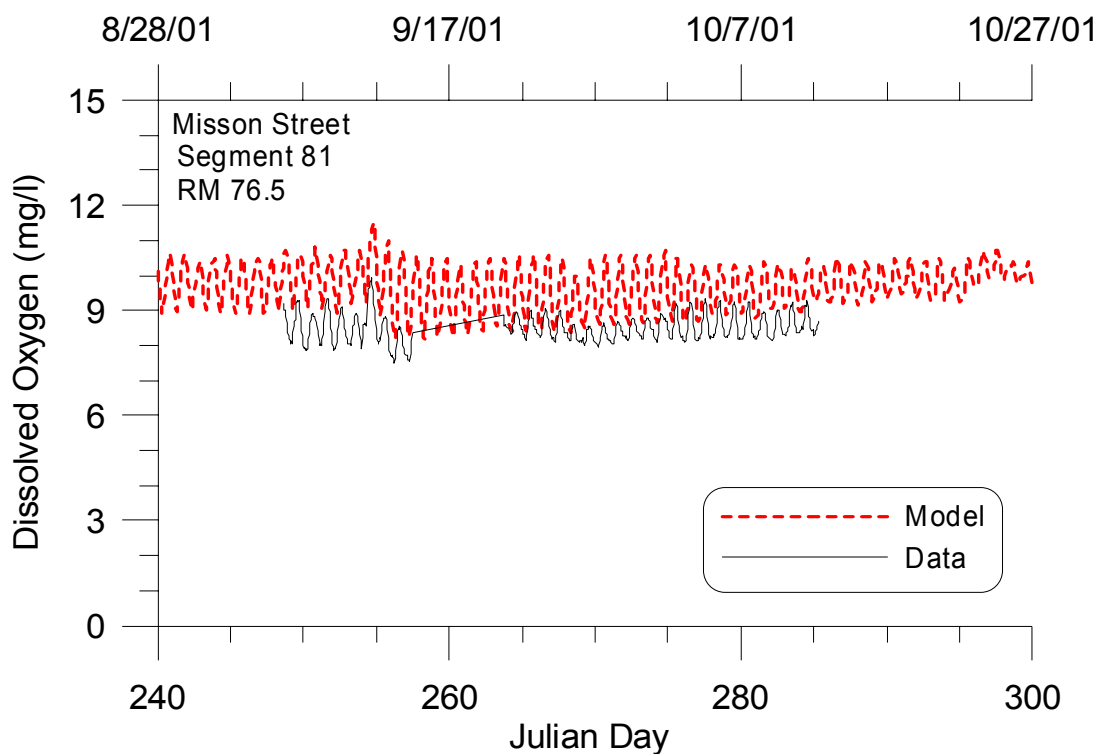


Figure 116. Dissolved oxygen predictions for Mission Street (RM 76.5) compared with continuous data.

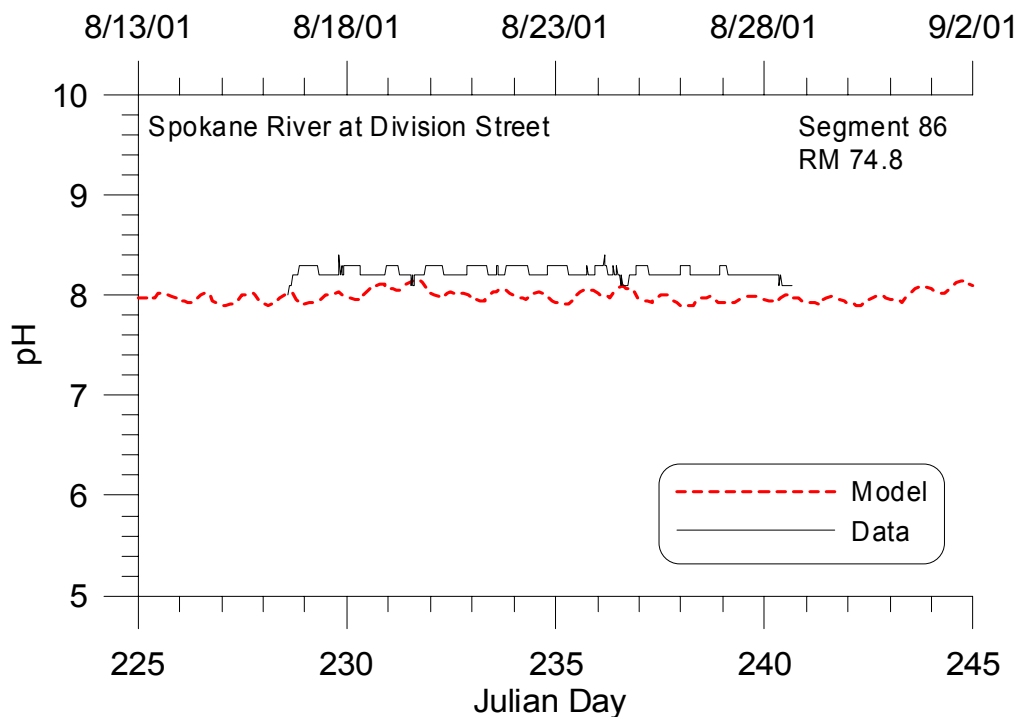


Figure 117. pH predictions for Division Street (RM74.8) compared with continuous data.

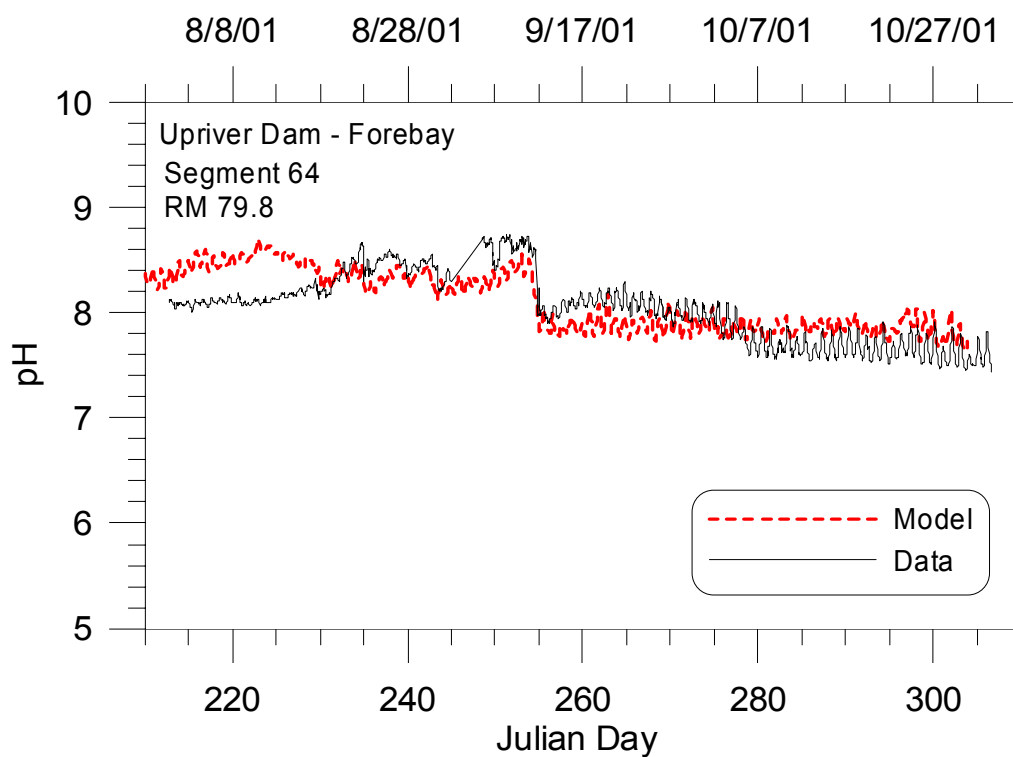


Figure 118. pH predictions for Upriver Dam Forebay (RM79.8) compared with continuous data.

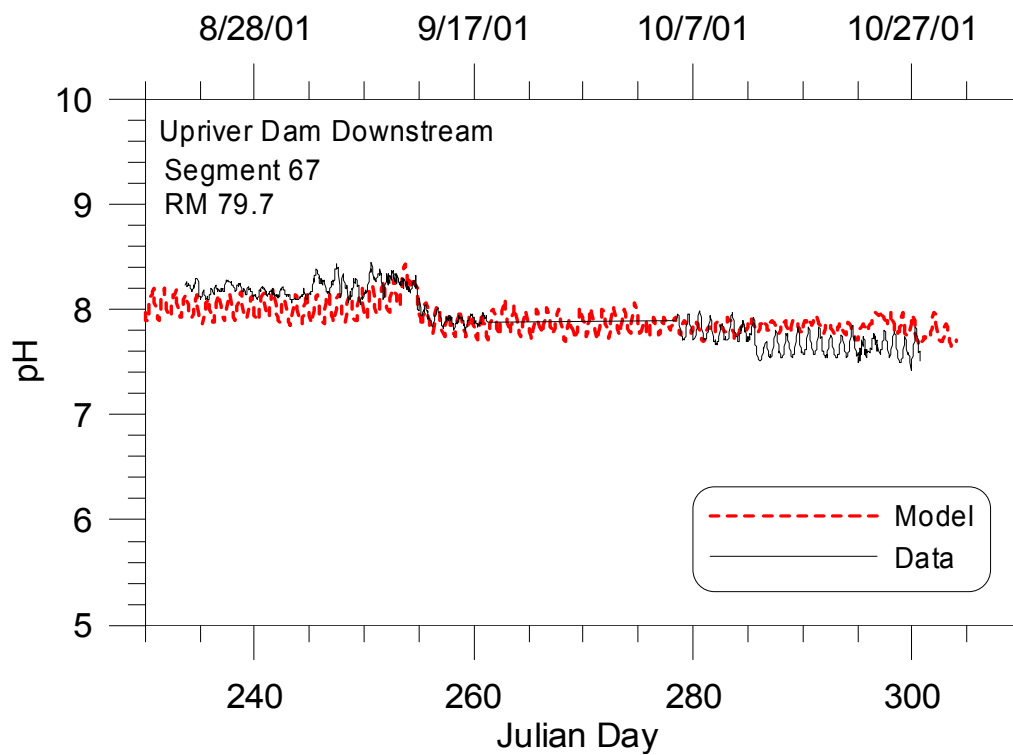


Figure 119. pH predictions for downstream of Upriver Dam (RM79.7) compared with continuous data.

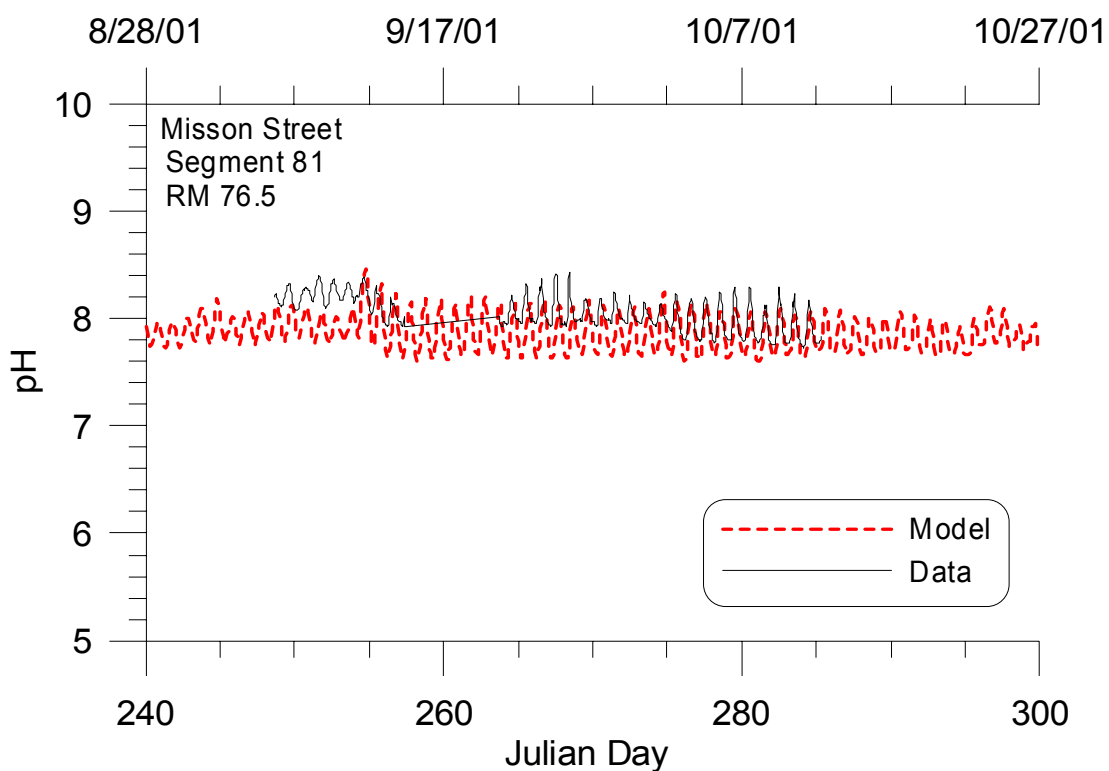


Figure 120. pH predictions for Mission Street (RM 76.5) compared with continuous data.

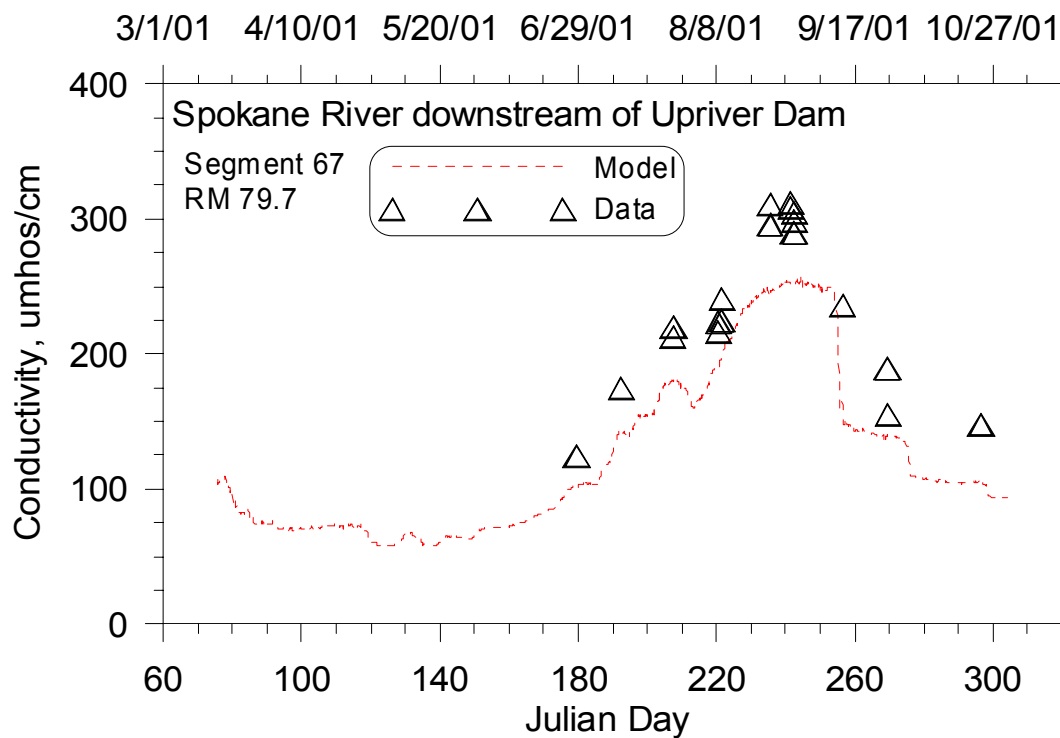


Figure 121. Comparison of model predicted conductivity and data downstream of Upriver Dam.

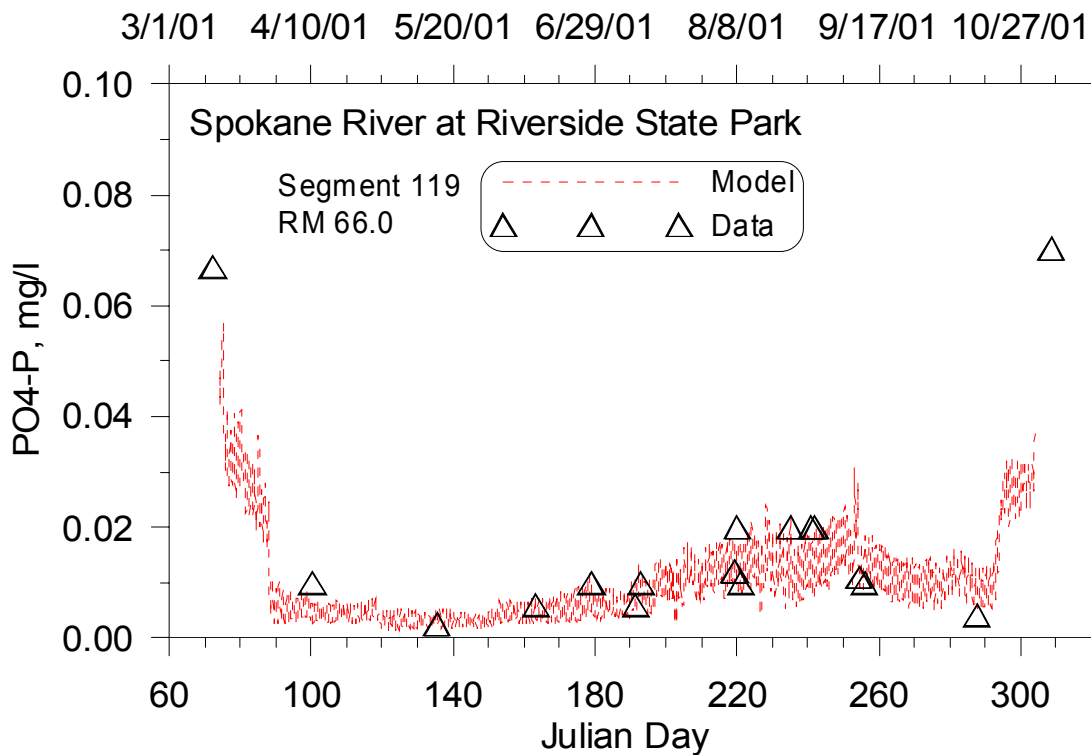


Figure 122. Comparison of model predicted soluble reactive phosphorus and data at Riverside State Park.

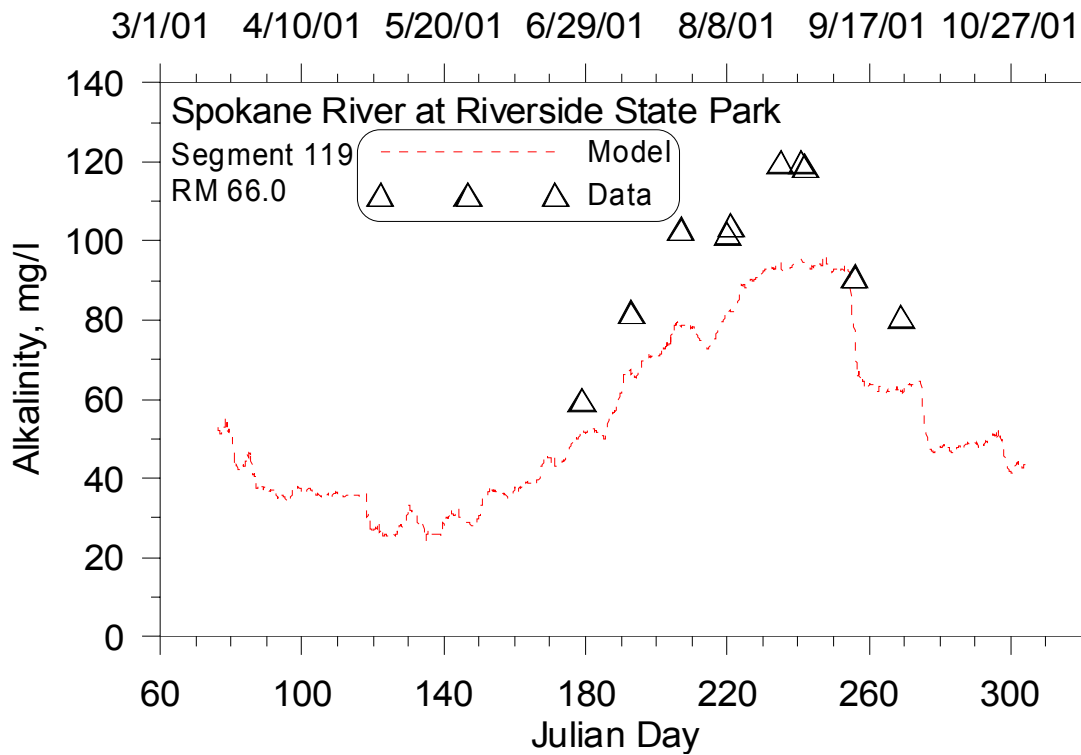


Figure 123. Comparison of model predicted alkalinity and data at Riverside State Park.



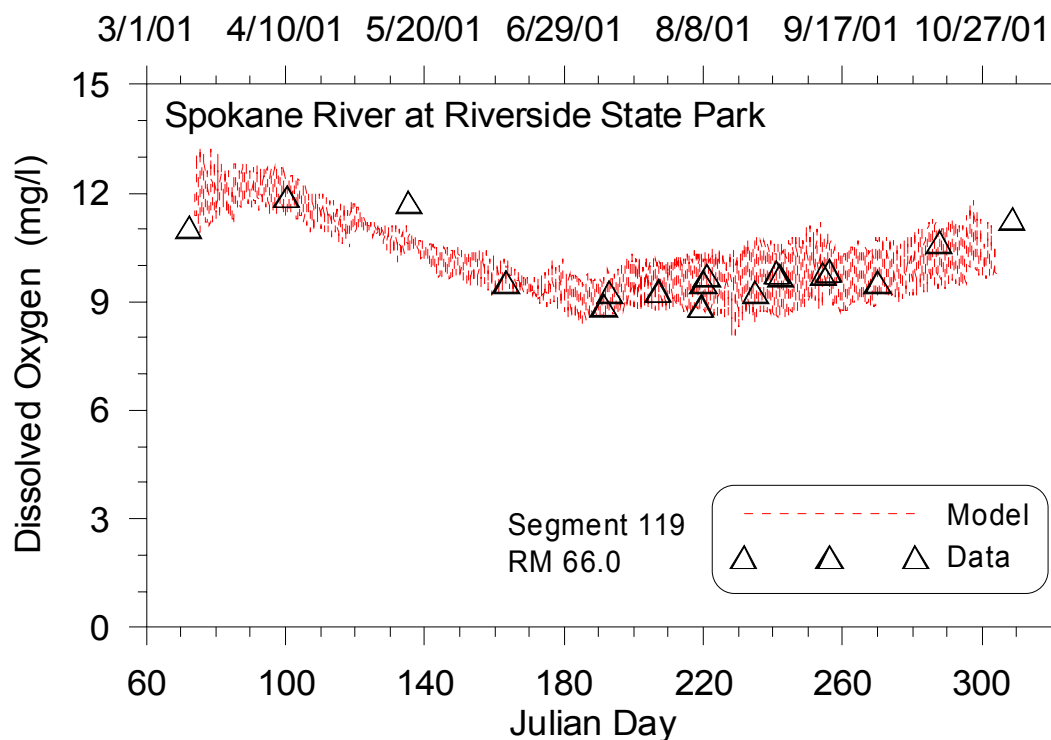


Figure 124. Comparison of model predicted dissolved oxygen and data at Riverside State Park.

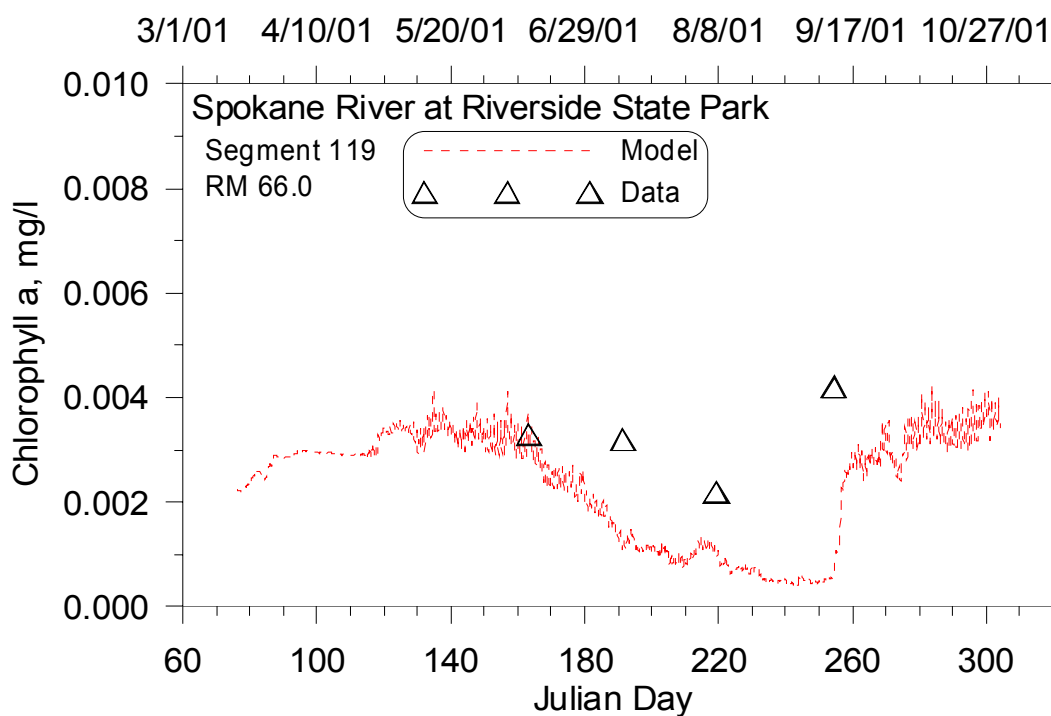


Figure 125. Comparison of model predicted chlorophyll a and data at Riverside State Park.

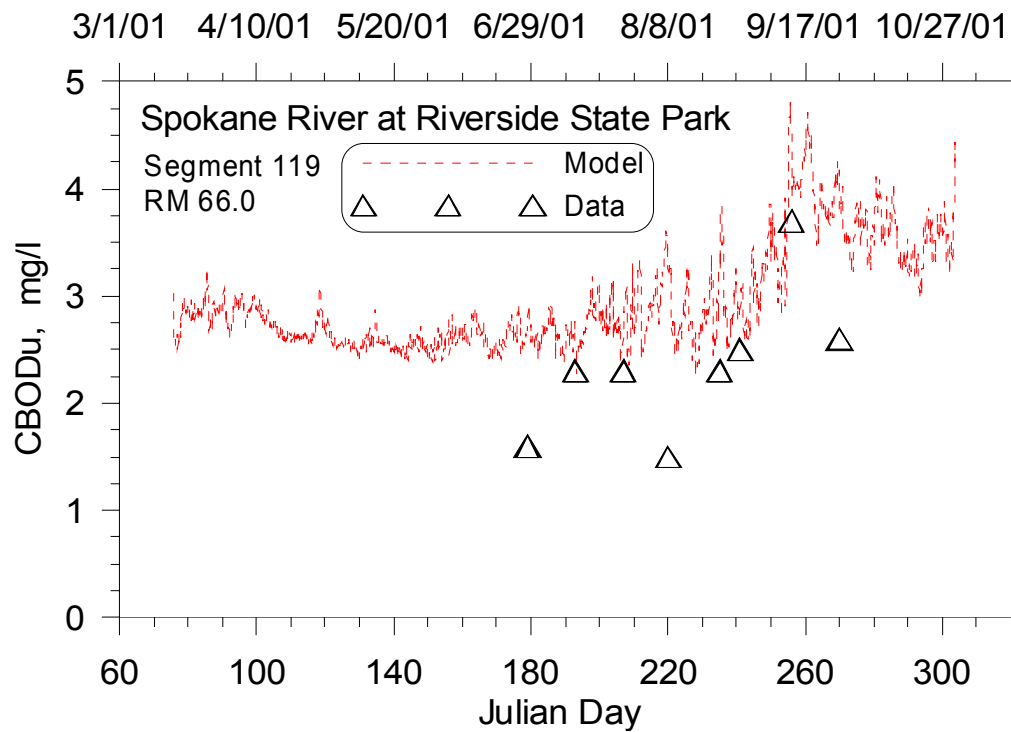


Figure 126. Comparison of model predicted CBOD ultimate and data at Riverside State Park.

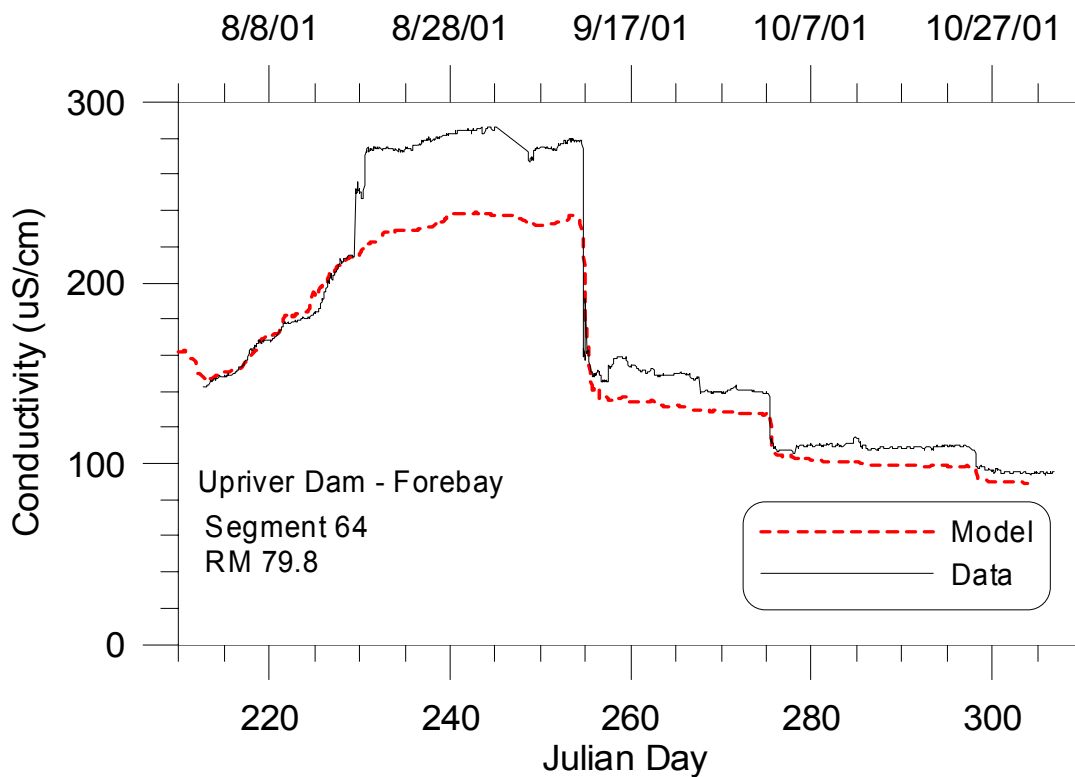


Figure 127. Comparison of model predicted conductivity and data for the Upriver Dam Forebay.

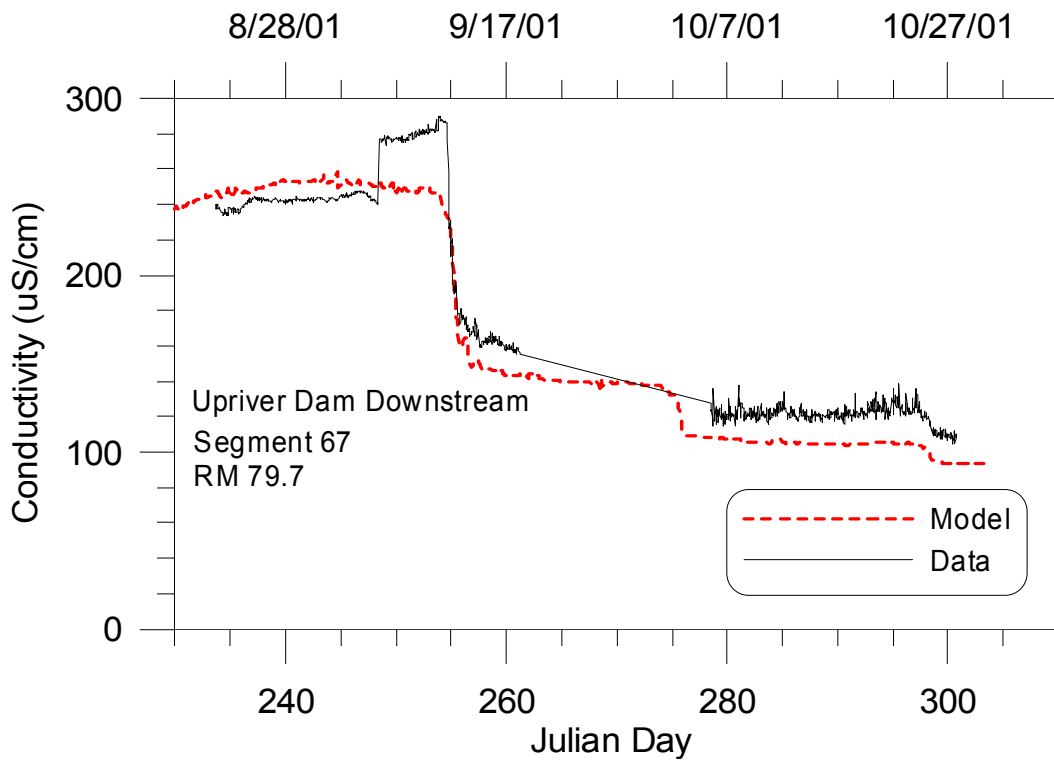


Figure 128. Comparison of model predicted conductivity and data for the downstream of Upriver Dam.

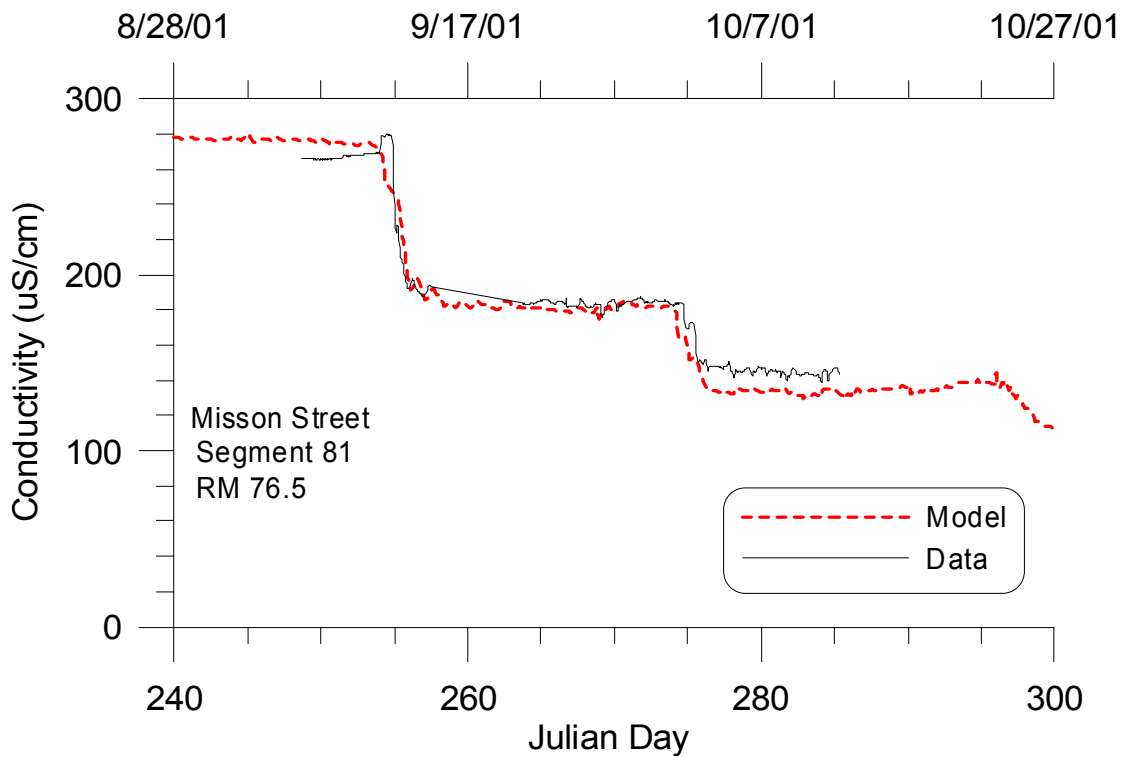


Figure 129. Comparison of model predicted conductivity and data for Mission Street.

## **Summary**

The files provided by Ecology as a calibration check were reviewed by PSU. The review process included

1. Reviewing modeling approaches used by Ecology to update the CE-QUAL-W2 model for the Spokane River.
2. Analyzing Lake Spokane (Long Lake) and algal growth in the upper sections of the lake.
3. Checking model simulations to verify results.
4. Modifying the boundary conditions and kinetic coefficients to improve model calibration where appropriate.

The changes that Ecology made to the 2001 model were largely an improvement in the model boundary conditions. This does not mean that further improvement in boundary conditions cannot be made, but these changes are based on existing data and we concur with the Ecology changes.

The addition of multiple algal groups in Long Lake was a way of realizing that the original model of Berger et al. (2003) used one algal group and was hence unable to replicate the typical late summer blue-green algal bloom that occurs in the upper reaches of Long Lake.

Using this additional algal group improved model predictions but the simulations still lacked several features evident in the data – accumulation of blue-greens at the upper end of the reservoir and larger biomass concentrations. By changing the wind direction for Long Lake, adjusting the rise rate of the blue-greens, and adjusting the P-blue-green stoichiometry, the model is now able to replicate much of the 2001 field data for the blue-green bloom.

The wind on Long Lake plays a large role in accumulating blue-greens in the late summer at the upper end of the reservoir. Field data of wind on the reservoir at several locations would assist in understanding that process.

However, the current set of algae kinetic and stoichiometric coefficients are not definitive at this point even though they agree with literature values. Also, we could have adjusted the algal coefficients further such that the pH on the surface of Long Lake was not so high (this is a function of growth rate and algae-C stoichiometry). But we left this as a further exercise if deemed necessary to support the TMDL. We recommend using the algae coefficients with the negative settling velocity for blue-greens (termed Run 1) since the model better reproduces field data (compared to Run 2).

## **References**

Annear, R., Berger, C., Wells, S., and Cole, T. (2001) "Upper Spokane River Model: Boundary Conditions and Model Setup," Technical Report EWR-4-01, Department of Civil Engineering, Portland State University, Portland, Oregon, 306 pages.

Berger, C., Annear, R. and Wells, S. (2003) Upper Spokane River Model: Model Calibration, 2001, Technical Report EWR-1-03, College of Engineering and Computer Science, Department of Civil and Environmental Engineering, Portland State University, Portland, Oregon.

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Slominski, S., Annear, R.L., Berger, C.J., Wells, S.A. (2002) "Upper Spokane River Model: Boundary Conditions and Model Setup for 2001," Technical Report EWR-02-02, Department of Civil and Environmental Engineering, Portland State University, Portland, OR.